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A a B C D E b F G H



I



II



III



IV



V

MINERAL

G. J. R. AND J. A. C. L.

EIGHTH EDITION,
REVISED AND ENLARGED.

BOSTON AND CHICAGO:
WOOLWORTH, AINSWORTH & CO.
1875.



FIGURE 1. THE EFFECT OF
WATER AND SOIL ON THE GROWTH OF PLANTS

WATER AND SOIL ON THE GROWTH OF PLANTS



A B C

The Cambridge Course of Physics.

ELEMENTS

OF

CHEMISTRY.

BY

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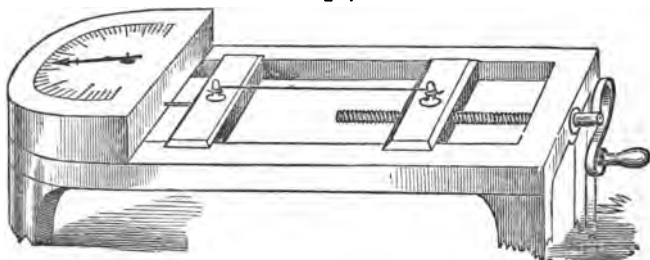
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as much force to pull asunder a rod of one of the solids as of another, the first is said to have twice the tenacity of the second.

The relative tenacity of solids may be determined by means of a machine called a *dynamometer*. This name is made up of two Greek words, and means *force-measurer*.

Fig. 4



One form of the machine is represented in Figure 4. It consists of a heavy iron frame, at one end of which is a box containing a stout steel spring. A pointer connected with this spring moves over a graduated arc on the top of the box. On the frame are two movable blocks, or slides, one of which is attached to the spring, while the other may be carried backward and forward by means of a screw and crank.

The rod whose tenacity is to be tried is stretched between the two slides, and the crank is then cautiously turned so as to pull upon the rod until it breaks. The force which is thus brought to bear upon the rod bends the spring; and the position of the pointer when the rod breaks shows how much force was required to pull the rod asunder.

12. *Hardness and Softness.*—If we indent a piece of india-rubber with the finger-nail, or strike a piece of lead a smart blow with a hammer, we see that it is possible to dis-

place the molecules of a solid. When it is easy to displace the molecules, as in the case of wax, the solid is called *soft*; when it is difficult to displace them, as in the case of glass, the solid is called *hard*.

To find which of two solids is the harder, see which will scratch the other. The one which scratches is always harder than the one scratched. Diamond is the hardest solid known. Because of its hardness it is used for cutting glass, which is also a very hard substance.

13. *Elasticity, Brittleness, Ductility, and Malleability.*—When molecules have been displaced, one of three results must follow,—they will return to their original positions as soon as they are left to themselves, or they will take up permanently new positions, or they will fall entirely asunder.

If we bend a steel rod moderately, it straightens as soon as it is released; showing that the molecules sometimes tend to return to their former positions after they have been displaced. This tendency of the molecules to return to their original positions is called *elasticity*.

We find on trial that a rod of glass, or even of pipe-clay, will straighten on being released after being slightly bent. Every solid has been found to be elastic.

A steel rod may be bent a good deal, and yet straighten when released; but if it be bent beyond a certain point it will no longer straighten, showing that the molecules, after they have been displaced beyond a certain limit, no longer tend to go back to their original positions. The greatest extent to which the molecules of a solid can be displaced, and yet go back to their original positions, is called the *limit of elasticity* for that solid. While all solids are elastic, they differ very much in the limit of their elasticity. The molecules of steel and india-rubber can be displaced a good deal and yet return to their original positions, while those of glass and pipe-clay can be displaced but slightly.

If a glass rod be bent within a certain limit it will straighten when released, but if it be bent beyond this limit it will not remain permanently bent, but will break ; showing that the molecules of a solid cannot always take up permanently new positions. When the molecules cannot take up permanently new positions, the solid is said to be *brittle*. Hard solids are likely to be brittle also ; but hardness and brittleness are, as we have seen, entirely different things.

When the molecules of a solid can take up permanently new positions, it is ordinarily described as *malleable* or *ductile*. It is said to be *malleable* when it can be hammered or rolled out into sheets ; *ductile* when it can be drawn out into wires.

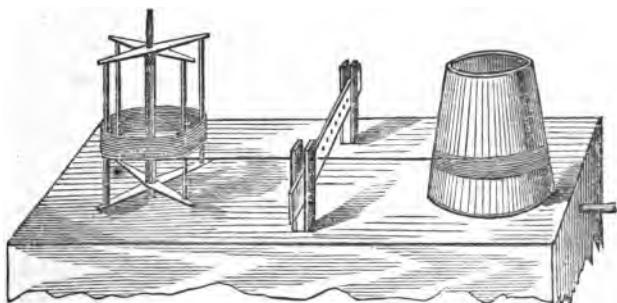
Gold is one of the most malleable of the metals. In the manufacture of gold leaf it is hammered out into sheets so thin that it takes from 300,000 to 350,000 of them to make the thickness of a single inch.

The gold is first rolled out into sheets by passing it many times between steel rollers in what is called a rolling-machine. The rollers are so arranged that they can be brought nearer and nearer to each other, pressing the gold into a thinner and thinner sheet every time it is passed between them. After it has thus been rolled out to the thickness of writing-paper, it is cut up into pieces about an inch square. These are piled into a stack with alternate pieces of tough paper, and beaten with wooden mallets. They are again cut up into small pieces and arranged in a stack with alternate squares of gold-beater's skin, and again beaten with mallets. This last process is usually repeated three times.

Wire is made by drawing a rod of metal through a series of conical holes in a hardened steel plate. Each hole is a little smaller than the preceding, so that the rod becomes lengthened and diminished in thickness as it is drawn through one after another. A machine for drawing iron

wire is represented in Figure 5. It consists of a reel on which the coarser wire is wound, a *drawing-plate* through

Fig. 5.



which it is pulled, and a drum on which it is wound again. The drum is turned by wheel-work, which is out of sight under the table.

The drawing of iron wire is attended with the following curious result. The molecules are separated in the drawing, yet the tenacity of the iron is greatly increased, so that fine iron wire is the most tenacious of substances. A bar one inch square of the best wrought-iron will sustain a weight of thirty tons; a bundle of wires one tenth of an inch in diameter, containing the same quantity of material, will sustain a weight of from thirty-six to forty tons; and if the wires have a diameter of only one twentieth or one thirtieth of an inch, the same quantity will sustain from sixty to ninety tons. Hence cables made of fine iron wire twisted together are much stronger than bars or chains of the same weight. The cables of suspension bridges are made in this way.

The following table gives the most useful metals in the order of their tenacity, malleability (both under the hammer and the rolling-mill), and ductility:—

Tenacity.	Malleability under the Hammer.	Malleability under the Rolling-Mill.	Ductility.
Iron	Lead	Gold	Platinum
Copper	Tin	Silver	Silver
Platinum	Gold	Copper	Iron
Silver	Zinc	Tin	Copper
Zinc	Silver	Lead	Gold
Gold	Copper	Zinc	Zinc
Lead	Platinum	Platinum	Tin
Tin	Iron	Iron	Lead

14. *Solids are somewhat Compressible.* — Pieces of oak, ash, or elm, plunged into the sea to the depth of 2,000 metres (about 6,560 feet) and drawn up after two or three hours, have been found to be compressed into about half their former bulk. Some metals are permanently diminished in bulk by hammering; and so also by the pressure to which they are subjected in the process of coining. The stone columns of buildings are frequently shortened by the great weight resting upon them. This was found to be the case with the columns supporting the dome of the Pantheon at Paris.

15. *The Arrangement of the Molecules.* — If alum be added to hot water as long as it will dissolve, and then the water be allowed to cool slowly, a part of the alum will be deposited on the bottom of the dish, not in a confused mass, but in beautiful and symmetrical forms. Such symmetrical forms are called *crystals*. If saltpetre, nitrate of baryta, or corrosive sublimate be treated in the same way, beautiful crystals will be formed, but in each case the crystals will have a different shape.

If sulphur be melted in a crucible, and then allowed to cool slowly till a crust forms on the surface, on carefully breaking the crust and pouring off the remaining liquid the crucible will be found lined with delicate needle-shaped

crystals. In the same way crystals of bismuth and many of the metals may be obtained.

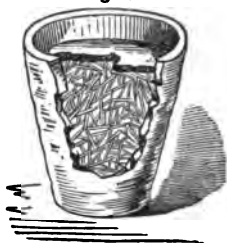
The cohesive force, then, not only holds the molecules of a solid together, but when it is free to act it often arranges these molecules in regular order, building them up into forms of great beauty.

In the cases of the formation of crystals which we have already described, the solid is first brought to the liquid state, and then allowed slowly to return to the solid state again. The solid was first reduced to a liquid that the molecules might have freedom of motion. The building of a crystal out of molecules is much like building a house out of bricks. The bricks must be taken one by one and laid in regular order before they are cemented together. So in forming a crystal, the molecules must be arranged one by one in regular order before they are fastened together by the cohesive force.

Large crystals of many solids can be obtained by dissolving as much of the solid as is possible in cold water, and then setting it away in a shallow dish where it will be free from dust and disturbance, and allowing the water to evaporate very slowly. The more gradual the formation, the larger are the crystals. The large crystals seen in cabinets of minerals were probably centuries in forming. The water in which the solid was dissolved found its way into a cavity of a rock and there slowly evaporated.

The tendency of the cohesive force to form the molecules into crystals is strikingly shown in cannon which have been many times fired, and in shafts of machinery and axles of car-wheels which are continually jarred. Such bodies often become brittle, and on breaking show the smooth faces of the crystals which have been formed. The continued jar-

Fig. 6.



ring gives the molecules a slight freedom of motion, and crystals are slowly built up.

Many solids are crystalline in structure which do not appear to be so. Thus a piece of ice, as we shall prove elsewhere, is a mass of the most perfect crystals, but they are so closely packed together that we cannot readily distinguish them. There is a large class of solids, however, as the fats, which cannot be crystallized.

16. *The Molecules cohere more strongly on some sides than on others.* — It is easy to cleave a piece of mica in one direction, but difficult to cleave it in other directions. The same is true of all crystals. It is much easier to cleave them in certain directions than in others. This is also the case with some substances which are not crystalline, as wood, which splits readily in one direction only. These facts prove that the molecules cohere more strongly on some sides than on others. Iron and other solids are not so tenacious when crystalline in structure as when not crystalline. This is because the molecules in crystals are arranged in layers, so that the weakest sides are brought face to face.

17. *Annealing and Tempering.* — If melted glass be dropped into cold water, it forms the well-known *Rupert's drops*, which are so brittle that, if we break off the small end or scratch them slightly with a file, they fly in pieces. When glass is allowed to cool in the air at the ordinary temperature, it is also very brittle. In order to make it tough enough for ordinary use, it must be cooled very slowly. This slow cooling of glass or other substances is called *annealing*. Glass is annealed by passing it slowly through a long oven, which is kept very hot at one end and cool at the other. It is usually about two days in passing through the oven.

Steel, also, when suddenly cooled from a high temperature, is very hard and brittle, but when slowly cooled it is very

tough and pliable. The process of bringing steel to the various degrees of hardness requisite for its uses in the arts is called *tempering*. Steel is usually tempered in the following manner. It is first heated white hot, and then suddenly cooled by plunging it into cold water. It is thus rendered very brittle. It is then reheated and allowed to cool slowly. When it is to be made quite hard, it is reheated but slightly; when quite soft, it is reheated a good deal. The more it is reheated, the softer it becomes on cooling. These different conditions of glass and steel are probably owing to differences in the arrangement of the molecules.

18. *Liquids*. The distinguishing characteristic of liquids is that the attractive and repulsive forces acting between the molecules are very nearly balanced, the attractive force being slightly in excess. Hence in liquids the cohesion is slight, and the molecules are free to move among themselves.

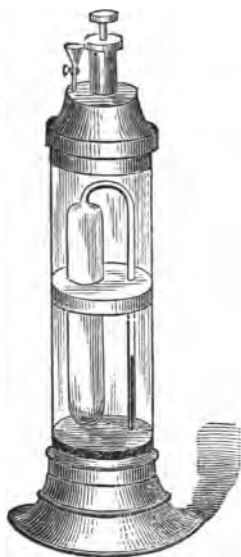
If a piece of lead be carefully measured, then melted and measured again, it will be found to have increased in bulk. The same is true of nearly all solids. Hence, when any substance is in a liquid state, the molecules are farther apart than when it is in a solid state. This explains why, in moulding bullets, the mould is never quite filled by the bullet.

There are, however, a few marked exceptions to this rule. It is well known, for instance, that if a bottle be filled with water and tightly corked, and allowed to freeze, the bottle will be burst. This shows that the molecules of ice are farther apart than those of water.

19. *Liquids are but slightly Compressible*.—The apparatus represented in Figure 7 consists of a very thick vessel of glass closed at top and bottom. Within the vessel are a piston which can be moved by the thumb-screw at the top, and a glass bulb which is prolonged by a very fine tube bent as represented. Fill the bulb and tube with any liquid,

as water, and plunge the end of the tube in the mercury

Fig. 7.



which covers the bottom of the vessel. Then fill the vessel with water, and apply pressure by turning the screw. The mercury will rise in the tube, showing that the liquid in the bulb has been compressed. This compression, however, is but slight, amounting at most to a few millionths of the bulk of the liquid.

20. *Liquids are perfectly Elastic.*

— However much the screw, in the above experiment, may be turned down, or however long it may be left, on loosening it the mercury will at once fall inside the tube to a level with the mercury outside ; showing that liquids are perfectly elastic. This elasticity is, however, developed only when the liquid is compressed, that is, when the mole-

cules have been brought nearer together. In whatever other way the molecules may be displaced, they show no tendency to return to their former positions.

21. *The Arrangement of Molecules in Liquids.* — If a mixture of water and alcohol be made so as to be just as heavy as sweet-oil bulk for bulk, and a quantity of the oil be carefully introduced into the centre of this mixture by means of a dropping-tube, the oil will neither rise nor sink, but gather into a beautiful sphere. This experiment shows that when the molecules of a liquid are left to themselves, they at once collect into spheres. What hinders the molecules of liquids from always taking this spherical form will be explained further on.

Rain-drops, dew-drops, and the manufacture of shot illus-

trate this tendency of the molecules of liquids. In the manufacture of shot, melted lead is poured through a sieve at the top of a very high tower, and the drops in falling take the form of spheres, which become solid before they reach the bottom.

22. *Gases.* — In gases, as has already been shown, the repulsive molecular force exceeds the attractive. Hence there is no cohesion in this state of matter, and the molecules move among themselves with greater freedom than those of liquids.

The molecules of any substance are farther apart in the gaseous state than in either the solid or liquid state. This may be shown by filling a test-tube nearly full of water, then closing it tightly with a cork through which a fine tube passes nearly to the bottom of the test-tube. On boiling the water so as to convert a portion of it into steam, which is a gas, the water is driven forcibly out of the fine tube; showing that the steam occupies more space than the water from which it comes.

Fig. 8.

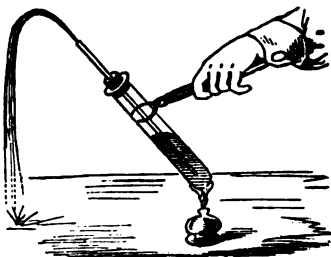
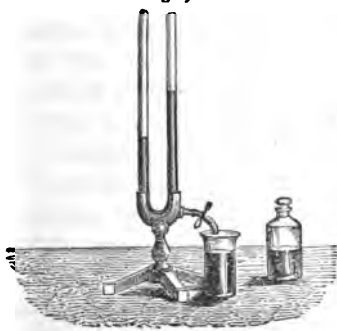


Fig. 9.



23. *Gases are readily Compressible and perfectly Elastic.* — The figure represents a U-tube closed at one end and open at the other, with a nipper-tap at the bend. Pour in mercury enough to cover the bend. The closed end is now filled with air. Pour in more mercury, and this

column of air rapidly shortens. The same would be true if the closed end of the tube were filled with any other gas ; showing that gases are highly compressible.

Open the nipper-tap that the mercury may run out, and it is entirely driven out of the closed arm of the tube. To prove that it is the elasticity of the air which drives out the mercury from this arm, fill the closed arm and a part of the open arm with mercury, and open the nipper-tap. The mercury will flow out from the open arm, and not from the closed arm. Gases, then, are perfectly elastic.

24. *The Molecular Constitution of Gases.* — When the molecules of any body are so far apart that the cohesive force exerts no constraint upon them, the substance is called a *true gas*. When the molecules are still somewhat under the restraint of cohesion, but not bound together by it, the substance is called an *imperfect gas*, or *vapor*. There are two characteristics of all true gases, which throw light upon their molecular constitution. "First, all true gases obey the same law of compressibility. Secondly, equal volumes of all true gases expand equally on the same increase of temperature." The repulsive force, then, which acts among the molecules, and tends to keep them apart, or to separate them, is the same for all true gases. This has led to the conclusion that *equal volumes of all true gases have the same number of molecules*.

SUMMARY.

Matter is made up of definite but insensible masses, called *molecules*. (1, 2.)

These molecules are not in actual contact with one another. (3.)

It is probable that the spaces which separate the molecules are immense in comparison with the size of the molecules themselves. (4.)

By trying to pull a solid in two we learn that there is an *attractive molecular force*, which holds the molecules together.

By placing a rubber bag partially filled with a gas under the receiver of an air-pump, and exhausting the air, we find that there is also a *repulsive molecular force*, which pushes the molecules apart. (5.)

Since the molecules of a solid may separate on being heated, and yet hold firmly together, we conclude that these two molecular forces *act together*, and that the *repulsive molecular force* is *increased by heat*. (6.)

We find that there are *three states of matter*, depending upon the relative strength of these two forces: the *solid* state, in which the attractive force is considerably the greater; the *liquid* state, in which the two forces are nearly equal; and the *gaseous* state, in which the repulsive force is the greater. (7.)

The force which holds together molecules of the *same* kind is called *Cohesion*; that which holds together molecules of *different* kinds, *Adhesion*. (8.)

Cohesion is the excess of the attractive over the repulsive molecular force. In *solids*, it is comparatively strong; in *liquids*, it is weak; in *gases*, it does not exist.

The properties of solids depend on the action of the cohesive force. (10.)

The *tenacity* of a solid is its power of resisting rupture. (11.)

A solid is called *hard* when it is difficult to displace its molecules; *soft*, when it is easy to displace them. (12.)

Elasticity is the tendency of the molecules, on being displaced, to return to their original positions. All solids are elastic, but differ greatly in the *limit* of their elasticity.

A solid is said to be *brittle* when its molecules cannot take up permanently new positions.

It is said to be *malleable* or *ductile* when they can take permanently new positions: *malleable*, when it can be hammered or rolled into sheets; *ductile*, when it can be drawn into wire. (13.)

Solids are somewhat *compressible*. (14.)

The cohesive force often arranges the molecules of a solid into regular forms, called *crystals*. (15.)

Crystals can be split more easily in some directions than in others, showing that the *cohesive force is stronger on some sides of the molecule* than on others. (16.)

The molecules are farther apart in the *liquid* than in the solid state; yet liquids are *less compressible* than solids. (19.)

Liquids are *perfectly elastic*; but their elasticity is developed only when the molecules are brought nearer together. (20.)

The molecules of a *liquid*, when acted upon only by cohesion, tend to collect into *spheres*. (21.)

In the *gaseous* state, the molecules are farther apart than in the liquid state. (22.)

Gases are readily *compressible*, and when compressed are *perfectly elastic*. (23.)

Equal volumes of all true gases have the same number of molecules. (24.)

A D H E S I O N .

25. *Adhesion between Solids and Solids.* — Adhesion has already been defined as the force which holds together unlike molecules.

The sticking of the chalk to the blackboard, of the graphite of the pencil to paper, and of dust to furniture, prove the existence of this force between solids and solids. The use of the various cements also illustrates this force, and also the fact that some solids adhere to a given solid more strongly than others. If we wish to fasten two pieces of wood together, we use glue ; if two bricks or stones, we use mortar, or some calcareous cement ; if two pieces of glass, sealing-wax, or some resinous substance. Stone adheres to mortar more strongly than wood or glass, and wood adheres to glue more strongly than stone or glass.

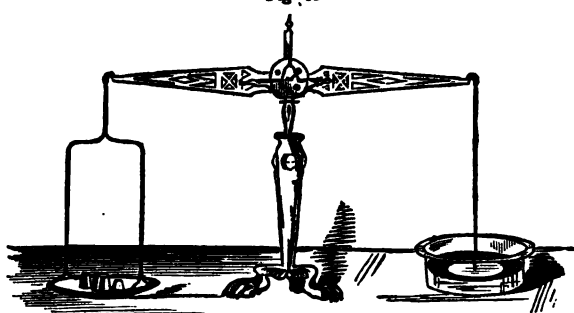
When solids are held together by cements, cohesion and adhesion are both brought into play. When, for instance, two pieces of wood are held together by means of glue, the adhesive force holds the wood on each side to the glue, and cohesion holds together the molecules of the glue.

When furniture breaks, we often see that the wood splits instead of separating from the glue. So also stones are sometimes cemented together so firmly that the stone itself will break sooner than separate from the cement. These facts show that the adhesive force between two solids is frequently stronger than the cohesive force of the solids themselves.

26. *Adhesion between Solids and Liquids.*—If we dip the hand in water it comes out wet. This, and similar facts equally familiar, prove that there is also an adhesive force between liquids and solids.

27. *The Adhesion between a Liquid and a Solid is sometimes not strong enough to overcome the Cohesion of the Liquid.*—If a glass disc be suspended from one pan of a balance and counterpoised by weights, and then brought in contact with

Fig. 10.



mercury, it will require additional weight to raise the disc from the mercury, and the disc comes off dry. This proves, first, that there is adhesion between glass and mercury, and, secondly, that this adhesion is not strong enough to overcome the cohesion of the mercury.

28. *The Adhesion between a Solid and a Liquid is sometimes strong enough to overcome the Cohesion of the Liquid.*—If a glass plate be laid upon the surface of water and then removed, it comes off wet, that is to say, covered with a film of water; showing that the adhesion between a solid and liquid is sometimes strong enough to overcome the cohesion of the liquid.

Since adhesion takes place only at the surface, it is evident that we may increase the adhesion of a solid for a liquid by increasing the surface of the solid.

If we take any solid, as a stone, and break it in two, the stone evidently has all the surface it had before it was broken, and, in addition, the two surfaces exposed by the breaking. Hence the more a solid is broken up, the more surface it exposes. The readiest way, then, to increase the surface of a solid is to pulverize it.

If pulverized bone-black be mixed with ordinary vinegar, or with wine, and the liquid be separated again by pouring the mixture upon a piece of unsized paper placed inside a funnel, every trace of color will be removed from the liquid. All vegetable colors can be removed from liquids in the same way. Removing the color from a liquid in this way is called *clarifying* the liquid.

Bone-black is obtained by burning bones in closed vessels. It is pulverized that it may present more surface. Other substances are sometimes used for clarifying liquids. Next to bone-black, or "animal charcoal," as it is sometimes called, ordinary charcoal is the best and the most frequently used. The bone-black evidently removes the coloring matter by means of the adhesive force which exists between the two. It is also evident that the coloring matter adheres to the bone-black more strongly than to the liquid, else the two would not be separated.

Use is made of this property of charcoal in the refining of sugar. The dark-colored syrup which is obtained from the cane is first filtered through long sacks filled with coarsely pulverized charcoal. In this way all the color is removed. The colorless syrup is then evaporated and forms white sugar.

29. *The Adhesion between a Solid and a Liquid is sometimes strong enough to overcome the Cohesion of the Solid.*—If some Epsom salts be put into water, the salts will speedily be reduced to the liquid state. The adhesive force between the water and the salts has evidently overcome the cohesive force of the solid, since it has reduced the solid to the liquid state.

30. *Summary.* — We have, then, three well-marked cases of adhesion between solids and liquids :—

1st. When the adhesive force is not strong enough to overcome the cohesion of the liquid. In this case the liquid *cannot wet* the solid.

2d. When the adhesive force is strong enough to overcome the cohesion of the *liquid*. In this case the liquid can *wet* the solid.

3d. When the adhesive force is strong enough to overcome the cohesion of the *solid*. In this case the liquid can *dissolve* the solid. The liquid which dissolves the solid is called a *solvent*, and the liquid in which the solid has been dissolved is called a *solution*.

31. *Heat promotes Solution.* — We find on trial that Epsom salts will dissolve more rapidly and in greater quantity in hot than in cold water. This is as we should expect, since we have already found that heat tends to overcome cohesive force. As a general rule, solids dissolve in greater quantities and more readily in hot than in cold liquids, but there are exceptions.

32. *Different Solids are not equally soluble in the same Liquid.* — If we put a piece of sealing-wax into water, it does not dissolve at all ; while water will dissolve about twice its bulk of Epsom salts. If we compare other solids in the same way, we shall scarcely find any two which dissolve with equal readiness in the same liquid.

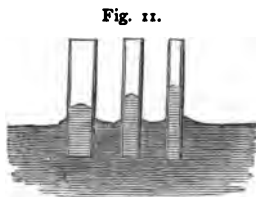
33. *The same Solid is not equally soluble in different Liquids.* — Sealing-wax, which does not dissolve in water, dissolves quite readily in alcohol. This shows that the same solid does not dissolve with the same readiness in different liquids.

34. *Capillarity.* — If one end of a fine and clean glass tube be put into water, the water will be seen to rise inside the tube above the surface of the water outside. If one end of a similar tube be put into mercury, the mercury will

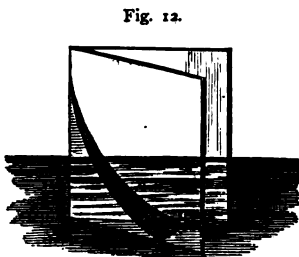
be seen to fall inside the tube below the surface of the mercury outside. This action of liquids inside tubes is called *capillarity*. The force which draws some liquids into tubes and pushes others out, has been called *capillary force*. This name is a convenient one, and we shall retain it, though, as we shall show elsewhere, capillarity results from the combined action of certain other forces.

We have seen already that water will *wet* glass, while mercury will *not*. We have, then, two well-marked cases of capillarity, corresponding to two cases of adhesion between solids and liquids; for those liquids which will wet a tube are drawn into it, while those which will not wet it are driven out. Mercury will wet zinc, and it is drawn into a tube of zinc, just as water is into a tube of glass.

We find by using glass tubes of different sizes, that the finer the tube, the higher the water rises and the lower the mercury falls, that is, the more marked is the capillarity. This fact explains the name. The word *capillary* comes from a Latin word (*capillaris*) which means *hair-like*. The force was called *capillary* because its action is most powerful in hair-like tubes. This



force, however, acts in tubes of every size, and in fact a tube is not necessary for its action; as may be seen by putting two plates of glass together as represented in the figure, and then dipping them into water or mercury. The water will rise between the plates, and the mercury fall.



35. *Illustrations of Capillarity.* — A lamp-wick is full of

tubes and pores, and capillary force draws the oil up through these to the top of the wick, where it is burnt. When one end of a cloth is put into water, capillary force draws the water into the tubes and pores of the cloth, and the whole soon becomes wet. In the same way a lump of sugar, or other porous substance, soon becomes wet throughout, if a corner of it is put into water. Blotting-paper is full of pores into which the capillary force draws the ink. The use of a towel for wiping anything which is wet depends on the same principle.

36. *Strength of the Capillary Force.*— It is well known that, when a piece of cloth is wet, it is almost, if not quite, impossible to wring or squeeze it dry. This shows that the capillary force which holds the water into the pores of the cloth is very strong. Some solids, as wood, swell on becoming wet. If holes are drilled into a granite rock, and dry wooden plugs driven into them, and water poured over the ends of the plugs, the capillary force draws the water into the pores of the wood, which swells and splits the rock. This is a striking illustration of the strength of the capillary force.

37. *Capillary Force never causes a Liquid to flow through a Tube.*— If a glass tube be so fine that the capillary force will draw water into it to the height of two inches, and the tube be then lowered so that not more than half an inch shall be above the surface of the water, the water will not overflow the tube. If, however, the water be removed as soon as it comes to the top, more will rise in the tube to take its place.

When a lamp is burning, the oil is passing up continually through the wick, because it is burned as soon as it reaches the top ; but when the lamp is not burning, the oil does not overflow the wick. The wick of an alcohol lamp must be covered with a cap when the lamp is not burning, otherwise the alcohol will evaporate as fast as it comes to the top of

the wick, and thus in a short time it will all escape from the lamp.

38. *Adhesion between Solids and Gases.*—If a small glass jar inverted over mercury be filled with ammonia gas, and a piece of boxwood charcoal, previously heated to redness and cooled by plunging it into the mercury, be introduced into the jar, the mercury rapidly rises into the jar, and, if the piece of coal is large enough, entirely fills it. The ammonia gas, then, has been drawn into the charcoal by an adhesive force; proving the existence of adhesion between the molecules of a solid and those of a gas. When a gas is taken up in this way by any substance, it is said to be *absorbed*.

If we try other solids instead of charcoal, we shall find that no two absorb ammonia gas with equal readiness.

If a piece of boxwood charcoal be introduced into a jar of air inverted over mercury, the mercury rises in the jar very slowly; showing that different gases are not absorbed with equal readiness by the same solid.

When the ammonia gas is absorbed by the charcoal, as in the above experiment, it evidently occupies less space than before. When a gas is absorbed by a solid, then, the repulsive force of the gas has to be overcome. We have already seen that cold helps to overcome the repulsive force. Hence we should expect that a solid would absorb a gas when cold more readily than when hot. Experiment shows this to be true.

Heat, on the other hand, increases the repulsive force. If a solid which has absorbed a gas be heated, the repulsive force of the gas is increased, so that it finally overcomes the adhesion of the solid for the gas, which then leaves the solid. The charcoal is heated before it is introduced into the jar, in order to drive all the air out of its pores.

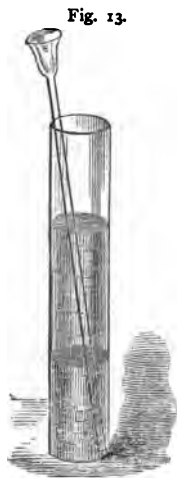
39. *Adhesion between Liquids and Liquids.*—If oil be poured upon water, the oil, which is the lighter, soon rises

to the top and remains entirely separate from the water. If, however, alcohol, which is also lighter than water, be poured into water, the two will thoroughly mix. This may be made evident to the eye by using colored water.

The fact that the alcohol remains mixed with the water proves that the molecules of the alcohol must adhere to those of the water, and that this adhesion is strong enough to overcome the cohesion of the liquids.

Nearly all liquids will mix when poured together, though some will mix much more readily than others.

40. *Diffusion of Liquids.* — If some colored alcohol be put into a tall glass jar, and then, by means of a funnel and a long tube reaching to the bottom of the jar, some water be carefully poured in, the water will remain a short time at the bottom of the jar, and its separation from the alcohol will be sharply defined. On standing a few days, the liquid will become of the same color throughout; showing that the alcohol and water have mixed. This mixing of liquids on being merely brought into contact is called *diffusion of liquids*. Different liquids diffuse into each other at very different rates, while some, as oil and water, will not diffuse at all.



41. *Osmose of Liquids.* — If a bladder be fastened air-tight to the end of a long glass tube, and the bladder be filled with alcohol and introduced into a vessel of water, the liquid will gradually rise in the tube; showing that the water has passed into the bladder. At the same time the alcohol passes slowly out and mixes with the water.

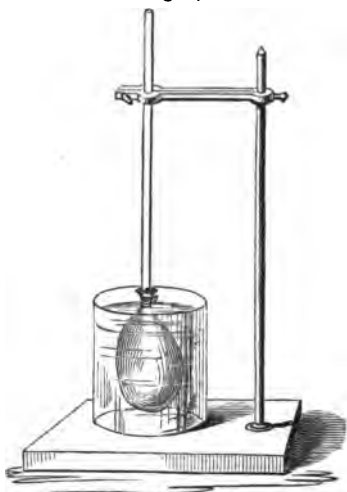
The mixing of liquids when separated by a thin membrane or porous substance is called *osmose of liquids*.

Liquids do not mix at the same rate when separated by a thin membrane or porous substance as when they mix by simple diffusion. The rate of mixing is modified in a striking manner by the presence of the membrane or porous substance. If, in the above experiment, we substitute a small collodion balloon for the bladder, the liquid will fall in the tube, showing that now the alcohol passes out more rapidly than water passes in.

The cases of osmose already given have been explained as the combined effect of capillarity and diffusion. In the first case, the water, which will wet the bladder much more readily than alcohol, is drawn by capillary force into the minute pores of the bladder, and thus is carried to its inner surface, where, coming in contact with the alcohol, it diffuses into it. As the water is thus removed as fast as it comes to the inner surface, a constant flow is maintained through the pores of the bladder. At the same time the alcohol passes out slowly by diffusing through the water which fills the pores of the bladder. In the second case, the alcohol wets the collodion more readily than the water does ; hence the more rapid flow is in the opposite direction.

Capillarity and diffusion, which explain these cases of osmose so satisfactorily, will by no means explain all cases. No satisfactory explanation has yet been given of the various ways in which the presence of the membrane affects the rate of mixing.

Fig. 14.



42. *Adhesion between Liquids and Gases.* — Let a small glass jar inverted over mercury be filled with ammonia gas, and then some water be poured over the surface of the mercury. If now the jar be carefully raised, the moment the mouth of the jar comes in contact with the water, the latter rises and completely fills the jar; showing that the ammonia has been absorbed by the water, and consequently that the molecules of the gas adhere to those of the water.

The same gas is not absorbed with equal readiness by all liquids, as is shown by the fact that ammonia gas, which is absorbed so greedily by water, is not absorbed at all by mercury. The same liquid does not absorb all gases with equal readiness, as is shown by inverting a jar of air over water. The air is absorbed scarcely at all.

43. *Cold and Pressure promote Absorption.* — When a gas is absorbed by a liquid, as well as when absorbed by a solid, the molecules are brought nearer together and the repulsive force overcome. Both cold and pressure, as we have seen, help to overcome this force; hence they favor the absorption of a gas by a liquid.

The effect of pressure on the absorption of a gas by a liquid is illustrated in soda-water. Soda-water owes its agreeable taste mainly to the presence of carbonic acid gas in the water. Water and carbonic acid are brought into contact in the fountain, and subjected to very great pressure. When the water is drawn from the fountain this pressure is removed, and the carbonic acid which had been taken up by the water escapes in thousands of little bubbles, causing the liquid to foam, or *effervesce*.

Ordinary liquid ammonia, or *aqua ammonia*, is a gas absorbed by water. If this liquid be heated, the ammonia gas escapes. The heat increases the repulsive force of the gas, and thus enables it to overcome its adhesive force for the liquid. The ordinary way to free a liquid from an absorbed gas is to heat it.

Common spring-water owes much of its pleasant taste to the presence of carbonic acid and other gases which it absorbs from the air. When this water is boiled, these gases escape, and it becomes very insipid. The constant agitation of running water helps it to absorb gases, since it is thus made to present more surface to the air.

44. *Diffusion of Gases.* — Two bottles are connected by a long glass tube. The lower bottle is then filled with carbonic acid and the upper with hydrogen gas, which is very much lighter than carbonic acid. After a time the hydrogen will be found to have passed down and mixed with the heavier carbonic acid, and the carbonic acid to have mixed with the hydrogen in the upper bottle.

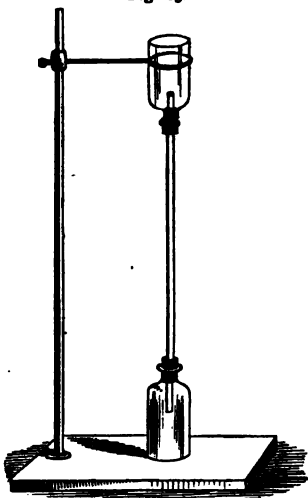
The presence of the carbonic acid in the upper bottle may be proved by pouring into it lime-water, which on shaking becomes of a milk-white color. Hydrogen has no effect upon lime-water.

The mixing of gases when brought into contact is called *diffusion of gases*.

Different gases diffuse into each other at very different rates. As a general thing, the more the gases differ in weight, the more rapidly will this diffusion be found to take place.

45. *Osmose of Gases.* — A long glass tube is fastened airtight, by means of a cork and sealing-wax, into the open

Fig. 15.



end of an unglazed porcelain cup such as is used in a Bunsen's or Grove's battery. The cup is then held so that the

Fig. 16.



end of the tube dips beneath the surface of water, and a large bell-jar of hydrogen is held over the cup. There is an instant rush of bubbles from the end of the tube up through the water, showing that the hydrogen has passed through the pores of the cup and mixed with the air inside. Remove now the jar of hydrogen, and the water at once rises in the tube, showing that the hydrogen inside the cup has passed out through the pores to mix with the air outside.

The mixing of gases when separated by a porous substance or thin membrane is called *osmose of gases*.

The diffusion and osmose of gases point to the existence of adhesion between molecules of different gases; but the existence of this adhesion has not been fully established.

SUMMARY.

Adhesion is the force which holds together molecules of *different kinds*.

It acts between molecules of solids and solids, solids and liquids, solids and gases; also between liquids and liquids, and liquids and gases. It is doubtful whether there is any adhesion between the molecules of different gases.

The adhesive force between two solids is sometimes greater than the cohesive force of the solids themselves. (25.)

There are three cases of adhesion between solids and liquids:—

1st. When the adhesion is not strong enough to overcome the cohesion of the liquid, and the liquid *cannot wet* the solid.

2d. When it is strong enough to overcome the cohesion of the liquid, and the liquid can *wet* the solid.

3d. When it is strong enough to overcome the cohesion of the solid, and the liquid can *dissolve* the solid. (26–30.)

Heat generally promotes solution, since it helps to overcome the cohesion of the solid. (31.)

The same liquid dissolves some solids more readily than others; while some liquids dissolve the same solid more readily than others do. (32, 33.)

Capillary force is a force acting upon liquids within tubes.

Liquids which can wet a tube are drawn into it by the action of this force, while liquids which cannot wet it are driven out of it.

The finer the tube, the more marked is the capillarity. (34.)

The capillary force is a very strong force; but acting

alone it never causes a liquid to flow *through* a tube. (36, 37.)

When a gas is absorbed by a solid or by a liquid, the adhesive force between the molecules of the solid or liquid and those of the gas must be strong enough to overcome the repulsive force of the gas. (38, 42.)

Heat hinders absorption, since it increases the repulsive force between the molecules of the gas. Hence gases absorbed by solids or liquids can be separated from them by means of heat. (38, 43.)

The same solid or liquid absorbs some gases more readily than others; while the same gas is absorbed by some solids or liquids more readily than by others. (38, 42.)

The adhesive force between the molecules of different liquids causes the liquids to mix. The mixing of liquids on merely coming in contact with each other is called *diffusion* of liquids. (40.)

Liquids also mix when separated by a thin membrane or porous substance. This mixing is called *osmose* of liquids. (41.)

Gases, like liquids, mix by *diffusion* and by *osmose*. (44, 45.)

CRYSTALLOGRAPHY.

46. *Symmetry of Crystalline Form.* — The general principle upon which the classification of crystals is founded is the *symmetrical arrangement* upon which every crystalline form is constructed.

Symmetry (that is, *similarity in the arrangement of two or more corresponding forms round a common centre*) is the general law of creation, both in the vegetable and animal kingdoms. It is exhibited in the correspondence in external form of the right and left side of the body in animals, in the similar arrangement of the leaf on either side of its midrib, in the two lobes of the dicotyledonous seed, and indeed it attracts the notice of every observer in numberless cases. The same law holds good still more rigidly, though not so obviously, in the constitution of every crystal.

The imaginary line which thus governs the figure, and about which all the parts are similarly disposed, and with reference to which they correspond exactly, is termed the *axis of symmetry* in a crystal. If a rhombohedron of Iceland spar be held with one of its obtuse angles uppermost, the vertical line which joins that angle to the opposite obtuse angle is the axis of symmetry of the crystal.

There are, however, crystals that possess more than one axis of symmetry ; and an arrangement of crystalline form, first proposed by Weiss, and now universally adopted, is based upon the relation which these axes bear to each other. These axes, it must be remembered, are *imaginary* lines, which connect the opposite angles or faces of a crystal, and all of them intersect each other in the centre of the figure.

47. *Classification of Crystals.* — Crystals are subdivided

into six classes or systems, founded upon the relation of their axes of symmetry to each other. These relations exert an influence not only upon the geometrical connection of the forms of crystals, but also upon their optical and physical properties. It is necessary in studying crystalline forms, the relations of which are often very complicated, always to place the crystal in a definite position. It will be found most convenient to place the principal axis in a vertical direction. The observance of this rule greatly facilitates the comparison of the compound with the simple forms.

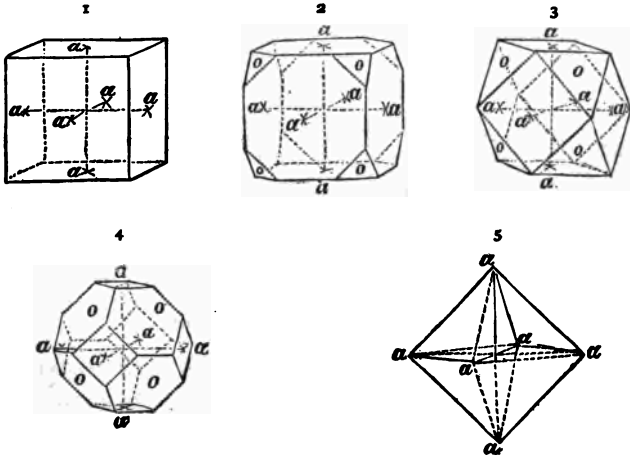
The six classes into which crystals are subdivided are the following : 1st, the Regular or Tessular system ; 2d, the Right Square Prismatic, or Pyramidal ; 3d, the Rhombohedral ; 4th, the Prismatic ; 5th, the Oblique ; 6th, the Doubly Oblique.

(1.) *The Regular, or Tessular, or Cubic System* is characterized by three equal axes, a, a, a (Figures 17, 18, 19), around which the crystals are symmetrically arranged ; they cross each other at right angles. Crystals belonging to this system expand equally in all directions when heated, and refract light simply. The most important varieties of simple forms are the cube, as shown in fluor spar, common salt, and iron pyrites (Fig. 17, 1) ; the octohedron (Fig. 17, 5), exemplified by alum and magnetic iron ore ; the tetrahedron (Fig. 19, 3), sometimes seen in copper ; and the rhombic dodecahedron (Fig. 18, 3), as in the garnet. Upon the geometrical relations of these forms, a single instance, showing one of the simplest cases of such a connection, will suffice : —

From the cube may readily be deduced the three other allied forms of the regular system. By truncating each of the eight solid angles by planes equally inclined to the three adjacent faces of the cube, we obtain the *octohedron*, in which the three axes of the cube terminate in the six

solid angles of the figure, one of which consequently corresponds to the centre of each side of the cube. (See Fig. 17.) The faces marked o are those of the octohedron.

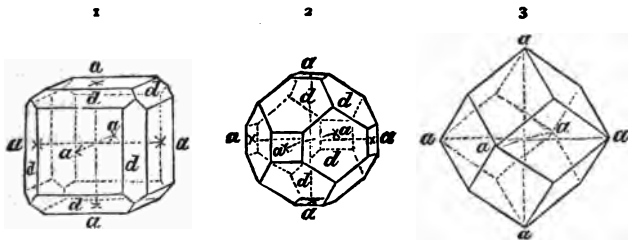
Fig. 17.



Passage of the Cube to the Octohedron.

By replacing each of the twelve edges, $d d d$, of the cube, we arrive at last at the *rhombic dodecahedron*. (Fig. 18.)

Fig. 18.

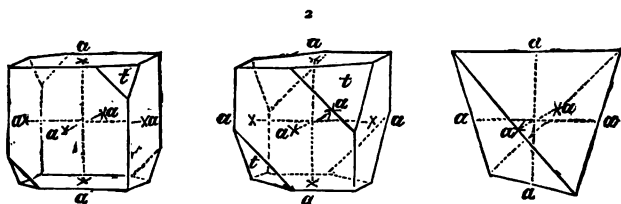


Passage of the Cube to the Dodecahedron.

By truncating the alternate angles, $t t$, we obtain the *tetrahedron*, as shown in Fig. 19.

Homohedral, or *Holohedral* forms, are those which, like the cube and octohedron, possess the highest degree of symmetry of which the system admits. *Hemihedral* forms, on the other hand, are those which may be derived from a holohedral form, as the tetrahedron is from the octohedron, or from the cube (Fig. 19), by supposing half the faces of

Fig. 19.



Passage of the Cube to the Tetrahedron.

the holohedral form omitted, or its alternate angles or edges replaced, according to a certain law. Again, if half the faces of a hemihedral crystal be omitted, a *tetartohedral* form is the result.

These relations will be readily traced, even by those unacquainted with geometry, by cutting out two or three cubes in soap or wax, and paring down the angles or edges in the manner above described.

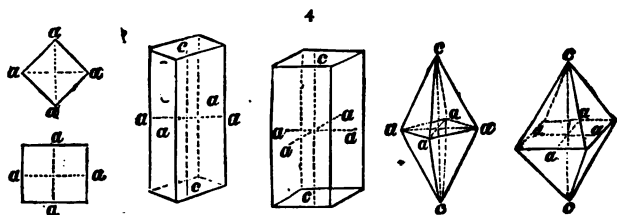
In a similar manner, by inserting wires into an apple we may represent to the eye the direction assumed by each of the axes of a crystal; and by winding a piece of thread round each point of the wires, and stretching the thread across from one wire to another, the outline of an octohedron belonging to any of the systems is readily obtained.

(2.) *The Right Square Prismatic, or Pyramidal System.*—In this system there are three axes, all at right angles to each other, but two only, $a a, a a$ (Fig. 20), are equal; the third, $c c$, being either longer or shorter than the others. Generally there is no simple relation between the length

of this axis and that of the other two. Expansion by heat is equal in two directions. The crystals of this system, as well as those of the four other systems not yet described, exert double refraction on light, and have only one axis of single refraction.

Four principal varieties of this system may be mentioned; two prisms with a square base, and two octohedra. The prisms differ from each other according as the equal axes $a a, a a$, terminate in the angles of the base, as seen in Fig. 20, 1; or in the sides of the base, as at 2. Similar

Fig. 20.



Pyramidal, or Right Square Prismatic System.

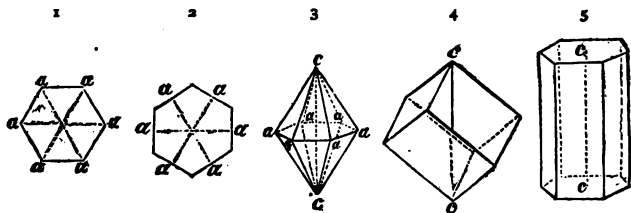
differences exist in the two octohedra. The octohedron is said to be *direct*, when the axes end in the angles, — *inverse*, when they end in the edges. 3 represents a right square prism, the axes of which terminate in the edges of the crystal; in 4, the axes terminate in the sides of the prism; 5 is the direct octohedron, with its axes in the solid angles; 6, the inverse octohedron, with the axes in the edges. Examples of this system are seen in potassic ferrocyanide (ferrocyanide of potassium) and mercuric cyanide (cyanide of mercury).

In consequence of the absence of any fixed relation in length between the principal axis, $c c$, and the other two axes, in the four different prismatic systems, these prisms may vary in length indefinitely. In some cases, the axis, $c c$, is so short that the crystal assumes the form of a

flattened plate, when it is said to be a *tabular* crystal ; in others, it forms a long prism of indefinite length. Even in the octohedron of the various prismatic systems, the principal axis, c , does not always bear the same proportion in length to the other two axes *in the same compound* ; though in these various octohedra, the axis, c , always bears some simple ratio in length to those of the other octohedra of the same body.

(3.) *The Rhombohedral System.* — In this system there are four axes ; three of them, a , a , a , are of equal lengths, are situated in the same plane, and cross each other at angles of 60° ; whilst the fourth, c , is perpendicular to these, and may vary in length. The crystals of this class produce, in a very marked manner, the effects of double refraction on light. They have one axis, c , of single refraction ; and by the application of heat expand equally in two directions. In this system the principal forms (Fig. 21) are the bi-pyramidal dodecahedron, 3 (of

Fig. 21.



Rhombohedral System.

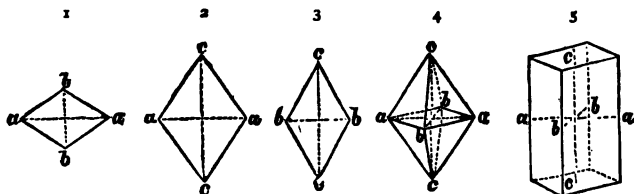
which there are two varieties according as the axes terminate in the angles of the base, 1, when it constitutes a direct dodecahedron ; or in its sides, 2, when the dodecahedron is said to be inverse), the rhombohedron, 4, and the six-sided prism, 5. Of each of these forms there are likewise two varieties, depending upon the position of the axes. 4 is an inverse rhombohedron. Among crystals

which belong to this system are ice, quartz, beryl, Iceland spar, and sodic nitrate (nitrate of soda).

The relations of the first three systems are simple, and easily traced; the other three systems are more complicated, owing to the variety introduced by the irregular lengths and obliquities of the axes.

(4.) *The Right Rectangular Prismatic, or Prismatic System.* — The crystals of this system have three axes, a a , b b , c c (Fig. 22), all at right angles to each other; each

Fig. 22.



Prismatic, or Right Rectangular Prismatic System.

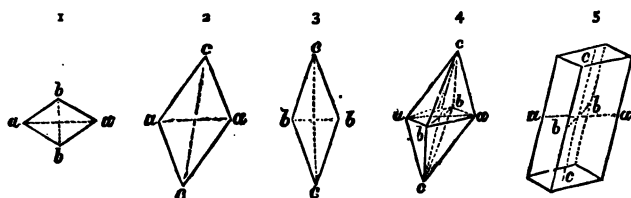
axis differs from the others in length, and they usually bear no simple proportion in length to each other. In this and in the two remaining systems, the crystals expand unequally by the application of heat, in the three directions of these axes; and they have two other resultant axes in which there is no double refraction.

The principal varieties of the prismatic system are the right octohedron with a rhombic base (Fig. 22, 4), or right rhombic octohedron; and the right prism with a rhombic base, or right rhombic prism, 5. Both these figures have a rhombic base, 1; the axes terminate in the solid angles of the octohedron, and in the edges of the prism. Owing to the inequality in the lengths of the axes, the sections of the octohedron through a b a b , 1, c a c a , 2, and c b c b , 3, though all rhombic in form, are each different in dimensions. The faces of the octohedron are all similar, but the length of each side of its triangular

faces is different. To this class belong nitre, aragonite, topaz, and sulphur obtained by evaporation from carbonic bisulphide.

(5.) *The Oblique System.* — The three axes of this system may all differ in length; two of them, $c c$, $a a$, cross each other obliquely (Fig. 23, 2); the third, $b b$, is perpen-

Fig. 23.



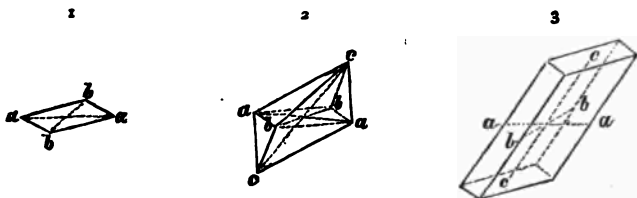
Oblique System.

dicular to both the others; generally there is no simple proportion between the lengths of the different axes. The principal forms are the oblique octohedron with a rhombic base, 4, and the oblique rhombic prism, 5, in both of which the axes are in the angles of the crystal. The base of the figure in each case is a rhomboid, 1, in which the axes $a a$, $b b$, cross each other at right angles. In the octohedron, the section through the two oblique axes, $a a$, $c c$, 2, is also a rhomboid; the axis, $c c$, crosses the third axis, $b b$, perpendicularly, and a section through these axes produces the rhomboid shown in 3. The octohedron of this system is not perfectly symmetrical. Each of the three sides forming its triangular faces differs from the others in length, and the faces are of two kinds. The two upper front faces of 4, Fig. 23, correspond to the two lower back faces, and the other four faces are alike. Besides the oblique rhombic octohedron, there are three forms of the oblique rhombic prism; the kind of prism being defined by the axis with which the long axis of the prism coincides. Sodic sulphate (sulphate of soda), sulphur crystallized by fusion

and slow cooling, borax, and ferrous sulphate (sulphate of iron) belong to this system.

(6.) *The Doubly Oblique, or Anorthic System.*—In this system, each of the three axes may differ from the others in length, and all cross each other obliquely. The principal varieties of crystalline form are the doubly oblique octohedron (Fig. 24, 2), the base of which is seen at 1, and

Fig. 24.



Doubly Oblique, or Anorthic System.

the doubly oblique prism, 3. The octohedron is not symmetrical in its form: its four upper faces are all unlike, but each face corresponds to the lower face which is parallel to it. Cupric sulphate (blue vitriol) belongs to this class, which is a comparatively small one. Some of the crystalline forms which it includes are very complicated, and difficult to define.

48. *Isomorphism.*—Owing to the comparatively small number of forms which belong to the regular system, and to the perfect symmetry which characterizes them, it necessarily happens that a variety of bodies, very dissimilar in properties and in chemical composition, assume crystalline forms which are not distinguishable from each other. For example, among the elements we find carbon, gold, and copper, and among compounds we find plumbic sulphide (sulphide of lead), fluor spar, and alum, all crystallizing in similar cubes or octohedra; yet the substances are otherwise very unlike each other.

Bodies which possess this similarity in form are termed *isomorphous* (from ἴσος, *equal*, μορφή, *form*). The term is, however, restricted to such substances as exhibit not only similarity in form, but at the same time an analogy in their chemical composition.

49. *Dimorphism*. — Some substances are capable of assuming two dissimilar forms, according to the temperature at which the crystals are produced. Sulphur, as it is found crystallized in nature, or as it is obtained by the spontaneous evaporation of its solution in carbonic bisulphide (bisulphide of carbon) is deposited in the form of octohedra with a rhombic base, which is one of the forms of the 4th, or prismatic system. When obtained by the slow cooling of a mass of melted sulphur, beautiful amber-colored prismatic crystals are obtained, belonging to the 5th, or oblique system. Bodies capable of thus assuming two forms geometrically incompatible are said to be *dimorphous*.

SUMMARY.

Crystals are *symmetrical* in form, their parts being similarly arranged about certain imaginary lines called *axes of symmetry*. (46.)

There are six *systems* of crystals, founded upon the relations of their axes of symmetry: the *regular*, the *right square prismatic*, the *rhombohedral*, the *prismatic*, the *oblique*, and the *doubly oblique*. (47.)

Substances which have the same crystalline form are called *isomorphous*; and those which crystallize in two dissimilar forms, *dimorphous*. (48, 49.)

CHEMICAL ACTION.

WATER.

50. *Action of Potassium and Sodium on Water.* — If a piece of potassium be thrown upon water, it burns with a rose-colored flame, and rapidly disappears. A piece of sodium when thrown upon water moves briskly about with a hissing sound, and soon disappears, but without flame. When, however, the sodium is kept still by putting it upon blotting-paper which lies upon the surface of the water, it burns with a yellow flame.

Fig. 25.

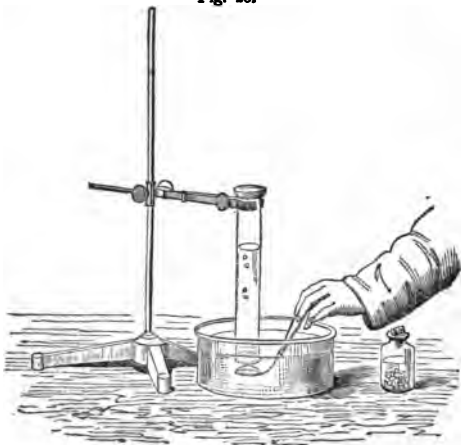


In both cases the metal disappears, and the water apparently remains unchanged. But if a strip of red litmus-paper be put into the water on which the sodium or potassium was burned, it turns at once to a blue color, showing that the water has also been changed ; for ordinary water has no effect on red litmus-paper.

If a piece of sodium be put into a small metallic cup pierced with holes and provided with a handle, and the cup be quickly introduced bottom upward under the mouth of a test-tube previously filled with water and inverted over a vessel of water with its mouth dipping beneath the surface, bubbles of gas rise from the cup and soon fill the test-tube.

If now the test-tube be raised from the water and a lighted taper applied to its mouth, the gas takes fire with a slight explosion, and burns with a pale bluish flame.

Fig. 26.



This gas is called *hydrogen*. Its extreme lightness, and the peculiar way in which it takes fire and burns, serve to distinguish it from other gases. Its lightness may be shown by the following simple experiment. Fill a test-tube with hydrogen and hold it mouth downward for some time; then apply a lighted taper, and it will still be found full of hydrogen. Fill it again and hold it mouth upward, and after a little time apply a lighted taper, when the hydrogen will be found to have wholly escaped. It is so light that it rises through the air as a cork rises through water.

51. *Whence does the Hydrogen come?* — In Figure 27 we have a U-tube open at both ends. In each of its arms is put a small graduated glass bell-jar. At the bend of the tube directly under each jar a platinum wire passes through the glass. This wire is flattened on the inside and terminates in a hook on the outside. The whole apparatus is

filled with water, and one of the platinum wires is connected with the zinc pole, and the other with the platinum pole of a Grove's battery. As soon as these connections are made, bubbles rise from each platinum wire, and the bell-jars slowly fill with gas.

When the jars are full, remove the one which has been connected with the zinc pole, and bring a lighted taper to its mouth. The gas takes fire with a slight explosion, and is recognized at once as hydrogen.



Remove the other jar, hold it mouth upward, and plunge into it a splinter of wood with a spark of fire on its end. The splinter at once bursts into a flame, and the gas does not burn. This gas is called *oxygen*.

We conclude, then, that the hydrogen in the previous experiment came from the water, and that it was set free by the sodium; and that besides hydrogen there is another gas in water called *oxygen*.

52. *Are these the only Substances found in Water?*—If a jet of hydrogen be burned in a jar filled with oxygen, and the heated gases be conducted through a cold glass tube, moisture collects on the sides of the tube, trickles down, and drops from the end, and may be caught in a wine-glass. This liquid resembles water; and if we drop a little of it on a piece of potassium, the latter takes fire and burns with a rose-colored flame, showing that the liquid really is water. This water can have been formed from nothing else than hydrogen and oxygen, hence there can be nothing else in water.

53. *Compound Substances and Elements.*—We see, then, that water can be separated, or *decomposed*, into two gases, hydrogen and oxygen. Substances which, like water, can be decomposed into other substances, are called *compound substances*.

It has hitherto been found impossible to decompose either hydrogen or oxygen. Substances which, like oxygen and hydrogen, cannot by any known process be decomposed into simpler substances, are called *elements*.

Only sixty-three elements are known, and thirteen out of this number, combining in various ways, make up almost the whole of the substances found in and about the earth.

54. *Chemical Force*. — The form of force which holds the elements in combination is called *chemical force* or *affinity*.

One characteristic of chemical force is that it not only unites different substances, but it unites them so as to form a new substance, often with wholly new properties. It *combines* them. Thus, when hydrogen and oxygen combine, they form *water*, a substance wholly unlike hydrogen, which is inflammable, and oxygen, which aids combustion.

A second characteristic of chemical force is that it always acts between *definite quantities* of matter.

If water be again decomposed in the U-tube by means of the battery, it will be noticed that the tube into which the hydrogen rises fills just twice as fast as the other. In whatever way water is decomposed, we always get just twice as much hydrogen as oxygen *by measure*.

Fig. 28.

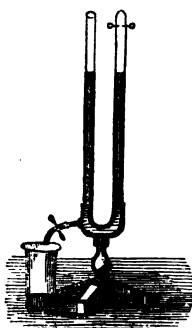


Figure 28 represents a U-tube, one arm of which is closed, the other open, with a nipper-tap at the bend. Two platinum wires pass through the closed arm near the top and almost meet within, while their outer ends are formed into loops for the attachment of battery wires.

Introduce into the closed end of this tube a mixture of hydrogen and oxygen, using first just twice as much hydrogen by measure as oxygen. Combine the

gases by means of the electric spark. Water is of course produced, and all the gases are used up, as is shown by the mercury's rising to the top of the tube.

If another mixture is used, in which we have more than two measures of hydrogen to one of oxygen, some hydrogen will be left over. If less than two measures of hydrogen to one of oxygen be used, some oxygen will be left. So that, in whatever proportions hydrogen and oxygen be mixed, we find that when they form water two measures of hydrogen always combine with one of oxygen.

55. *Chemical Force is stronger between some Substances than between others.* — When potassium is thrown upon water (50), it unites with the oxygen and sets the hydrogen free; showing that the chemical force between potassium and oxygen is stronger than between hydrogen and oxygen. In general, if to a compound of two elements, A and B, a third element, C, be added, which has a stronger affinity for A than A has for B, A will leave B and combine with C.

ATOMS.

56. *Hydrogen and Oxygen condense one third when they combine.* — We have already found that two volumes of hydrogen always combine with one volume of oxygen to form water.

When they are thus made to combine in a space whose temperature is such that the water formed shall exist as a true gas (24), its volume is found to be two thirds that of the mixture.* Hence just as many molecules of water are formed as there were of hydrogen, and twice as many as

* Such a space can be obtained by surrounding the end of the U-tube which holds the mixture with a larger glass tube through which the steam from fusel oil is made to pass. The temperature of this steam is above that of boiling water.

there were of oxygen, in the mixture. And, as all the molecules have the same composition, each molecule of oxygen has been divided into two equal portions. Again, when potassium is thrown upon water, some of the hydrogen is set free and replaced by the metal used. When the new compound formed is examined, it is found to be made up of hydrogen, potassium, and oxygen. But, while water contains 16 parts by weight of oxygen to 2 of hydrogen, this new compound contains only 1 of hydrogen to 16 of oxygen. Hence the potassium displaces only half the hydrogen from each molecule of water, or, in other words, it divides the hydrogen molecule. We see, then, that *the molecules themselves are divisible*.

57. *Molecular and Atomic Constitution.* — The astronomer finds that the universe is made up of stars, or suns, each of which is probably, like our own sun, the centre of a solar system made up of planets. These solar systems are the larger units, or individuals, of the universe ; and the planets are the smaller units of which these systems are composed. Some of these smaller units, as Venus and Mars, are simple ; others, as the Earth and Jupiter, are complex, being made up of a planet and one or more moons. We now believe that all the bodies about us are made up of units analogous to these. The physicist finds matter to be made up of separate and distinct masses, or units, which he calls *molecules*. He cannot see these even with the aid of the microscope ; but he is as certain of their existence as the astronomer is of his planets and solar systems. The chemist pulls these molecules in pieces, and finds that they are made up of smaller units, which he calls *atoms* or *compound radicals*, according as they are simple or complex. He believes that in most cases the molecules of the elements, as well as of compounds, are made up of two or more atoms ; the only difference being, that in the one case the atoms are all

alike, while in the other they are not. Thus a molecule of hydrogen is believed to be made up of two atoms of hydrogen ; while a molecule of water is made up of two atoms of hydrogen and one of oxygen. When a molecule of water is broken up, it ceases to be water, and becomes hydrogen and oxygen. Hence we may define a *molecule* as *the smallest mass of a substance which can exist by itself*; and an *atom* as *the smallest mass of any substance which can exist in a molecule*.

The molecules of a body are bound together by *cohesion*, and the atoms by *affinity*. The molecules of a solid, as a general rule, tend to arrange themselves in regular order, so as to build up symmetrical forms called *crystals* (15).

It is probable that the *atoms* when bound together by *affinity* tend to arrange themselves with equal regularity ; but as yet we are ignorant of the mode of arrangement. Indeed, the *number* of atoms in the molecules of many substances is as yet a matter of mere hypothesis.*

58. *Symbols*. — Certain abbreviations of the names of the elements are much used in chemistry. These are called *symbols*, and are often based on the *Latin* name of the element. Thus the symbol of oxygen is O ; of hydrogen, H ; of potassium (Latin, *kalium*), K, etc. The symbol of a compound is made up of the symbols of its elements. It also indicates the atomic constitution of the molecules of the compound. The symbol of each element represents *one atom* of that element. If there is more than one atom of the element in the molecule, this is indicated by a small figure placed at the right of the symbol. Thus the symbol of *water* is H_2O , since water is a compound, whose molecule contains two atoms of hydrogen and one of oxygen.

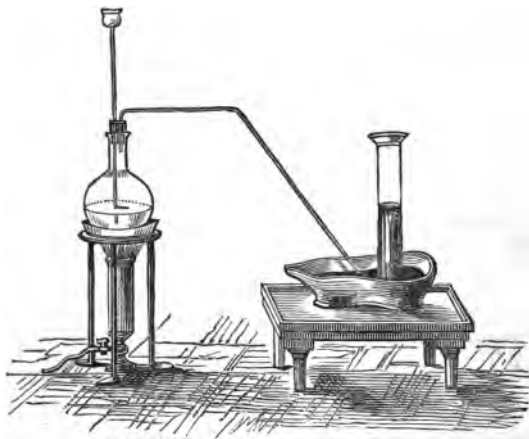
* Although we know nothing of the actual *position* of the atoms, we do know something of the *structure* of the molecule, since we know the manner in which the combining units are disposed of (page 68).

MURIATIC ACID.

59. We will next examine a liquid commonly called *muriatic acid*. It somewhat resembles water in appearance, and, though not so well known, has for a long time been extensively used in the arts.

Put some muriatic acid into a flask, and connect the flask by means of a tube with a glass jar filled with mercury and inverted over the mercury trough, as shown in

Fig. 29.



the figure. Boil the acid, and a gas will pass over and fill the jar. If now the jar be removed and its mouth be opened under water, the gas will be quickly absorbed, and the water will have all the properties of muriatic acid.

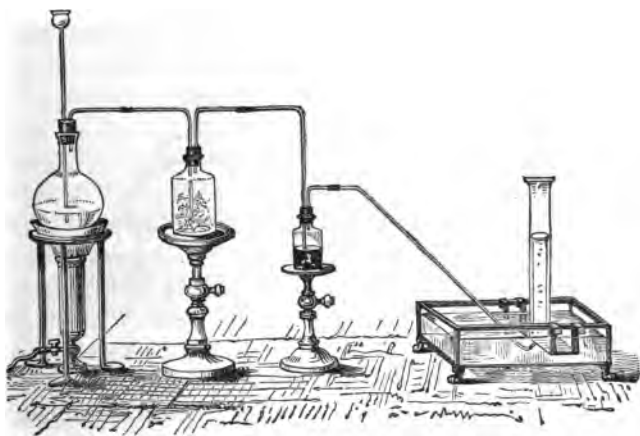
We therefore conclude that ordinary muriatic acid is a gas reduced to the liquid state by being absorbed by water. It is thus made liquid merely for convenience in using and transporting it.

When this muriatic acid is boiled, steam will be generated and pass over with the gas.

We have seen that a solid absorbs some gases much more readily than it absorbs others. If we can find a solid which will absorb steam and not absorb muriatic acid gas, we evidently can separate these two gases by causing them to pass together over this solid. *Fused calcic chloride* (chloride of calcium) is such a solid. We break it up into coarse lumps, that it may expose the more surface to the gases, and put it into a glass tube or a tall and narrow glass jar. Such a tube or jar is called a *drying-tube* or *drying-jar*.

If some muriatic acid be again boiled in a flask, and the muriatic gases which escape be conducted, as shown

Fig. 30.



in the figure, first through a drying-jar, to remove the steam, and then through a bottle partially filled with *sodium amalgam* (sodium dissolved in mercury), and then into a jar filled with water, and inverted over the water-trough, the gas which collects in this jar will be found to

be wholly unlike muriatic acid gas. It is no longer absorbed by water, and has no effect on blue litmus-paper. Muriatic acid gas is not inflammable, but if this gas be tested by bringing a lighted taper to the mouth of the jar after raising it from the trough, it takes fire with a slight explosion, and burns with a pale blue flame. This shows the gas to be hydrogen.

60. *Composition of Muriatic Acid.* — We see, then, that muriatic acid is a compound substance, and that one of the elements of which it is composed is hydrogen. We must next find what element or elements the sodium has removed from the acid. The mercury in the amalgam takes no part in the decomposition of the gas. The sodium is dissolved in the mercury merely that it may present more surface to the gas.

Taking the same apparatus used for decomposing water by means of the battery, fill it with dilute muriatic acid, and connect it with the battery as before. The bell-jar connected with the zinc pole is filled quite rapidly with a gas which is found on trial to be hydrogen. The other jar, after some time, begins to fill with a gas of a yellowish-green color. This gas has a peculiarly suffocating odor, and the remarkable property of bleaching vegetable colors. This latter characteristic may be shown by raising the jar filled with the gas, inverting it, and putting into it a piece of moistened litmus-paper, which very soon loses all its color.

This gas from its color is called *chlorine*; a name derived from a Greek word meaning *yellowish-green*. Its color and its bleaching properties serve to distinguish it from other gases.

If a jar of chlorine be inverted over water, it is slowly absorbed. This is the reason that, when muriatic acid is decomposed by means of the battery, the chlorine does not at first collect in the bell-jar.

61. *Are Hydrogen and Chlorine the only Elements in Muriatic Acid?*—Take two glass jars of the same size, with ground mouths, fill one with hydrogen and the other with chlorine, and place them together mouth to mouth, as represented in Figure 31. Then withdraw the glass plates by which they are closed, shake the jars to mix the gases, and open them over a burning lamp. The mixed gases take fire, and the appearance of a white cloud shows that muriatic acid is formed by their combustion.* Hence this acid can contain only hydrogen and chlorine.

Fig. 31.

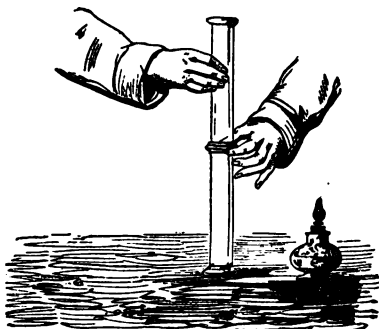


Fig. 32.



62. *There are equal Volumes of Hydrogen and Chlorine in Muriatic Acid.*—Figure 33 is a decomposing cell, which is closed with a rubber cork through which pass two platinum wires and a bent glass tube. To the wires are attached strips of platinum foil. Fill the cell with strong muriatic acid, and connect it with a Grove's or Bunsen's battery of five or six cups. The muriatic acid will be

* If a dish of ammonia is standing near by, the white fumes will be much more dense.

decomposed into hydrogen and chlorine, which will escape together through the delivery tube. Allow the decomposition to go on for some time, until the muriatic acid has

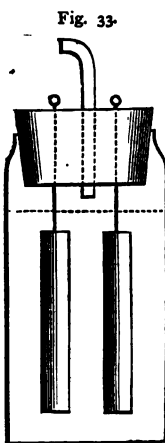


Fig. 33-

become completely saturated with chlorine; then connect the delivery tube with the top of the long *absorption tube* (Figure 34), and allow the mixed gases to pass through it until all the air is driven out.* Now slip the rubber connecting tube from the top of the absorption tube, and keep the small tube passing through the cork closed with the thumb; pinch the rubber tube at the bottom close, and plunge the lower end of the absorption tube under a solution of soda of the ordinary strength (sp. gr.

Fig. 34-



1.12) and remove the lower cork. The soda gradually absorbs the chlorine and rises in the tube. When it has risen some two inches, the tube, while its mouth is still under the soda, is again closed with a whole rubber cork. The soda in the tube is then turned backward and forward a few times, and the tube again opened under water. The soda has absorbed all the chlorine, and the water fills the tube just half full. The gas remaining in the tube is found, on trial, to be hydrogen. Of course it is necessary, in this experiment, that the corks should fit air-tight. On turning the soda backward and forward, a leak can be easily detected by the bubbles of air which will pass in around the corks.

* The mixed gases should not be allowed to escape into the room, but should be conducted into a jar over the water trough.

63. *Hydrogen and Chlorine combine without Condensation.*

— Pass the delivery tube of a gas-generating apparatus down the open limb of a U-tube (Figure 35) in such a manner that the gas bubbles up through the mercury into the sealed limb. An appropriate quantity of dry muriatic acid gas having been thus introduced, the nipper-tap is closed, and mercury is poured into the apparatus, until it stands at the same level in both limbs. The space occupied in the tube by the gas is then marked in any convenient way.

Fig. 35.



That portion of the open limb which is unoccupied by mercury is then filled with sodium-amalgam, and the end of the tube is closed by the thumb. The gas may now, by inclining the tube, be easily transferred from the sealed to the stoppered limb; traversing, in its passage, the column of sodium amalgam, and being thereby decomposed. To insure complete decomposition, the apparatus should be once or twice shaken, so as to bring every portion of the gas into thorough contact with the amalgam; after which, by reversing the previous inclination of the tube, the gas may be re-transferred to the sealed limb of the apparatus. On removing the thumb from the mouth of the open limb, the mercury falls a little therein, and may be further lowered by opening the nipper-tap. As soon as the mercury stands at a uniform level in the two limbs, the gas is found reduced to exactly half its original volume. The gas which remains is found to be hydrogen.

This experiment shows us that any given bulk of muriatic acid contains half that bulk of hydrogen. The other half is of course chlorine. Hence, hydrogen and chlorine combine without condensation.

64. *Atomic Constitution of Muriatic Acid.*—Hence when hydrogen and chlorine combine to form muriatic acid, there are just as many molecules of the muriatic acid as there were of the hydrogen and the chlorine; showing that the molecules of the hydrogen and the chlorine have each been divided into two equal parts, and, as it is not possible to divide a molecule of chlorine into more than two parts, we conclude that a molecule of muriatic acid contains two atoms, one of hydrogen and one of chlorine.

The symbol of chlorine is Cl. That of muriatic acid evidently will be HCl.

AMMONIA.

65. The ammonia of commerce, like the muriatic acid, is a gas absorbed by water, as may readily be shown by the method described under muriatic acid (59).

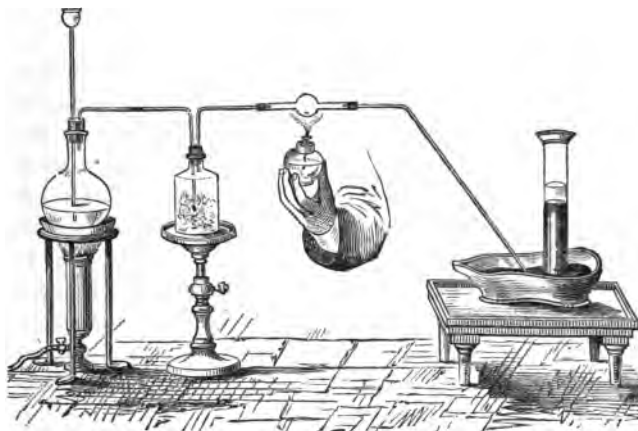
If some ammonia be boiled in a flask, steam and ammonia gas will pass off. If these gases are then passed through a drying-jar filled with unslaked lime (Figure 36), the steam will be retained, and the ammonia gas will pass on. If this gas be then conducted into a test-bulb in which there is a piece of heated potassium, and the gas which leaves the tube be collected in a small jar, it will be found by the usual test to be hydrogen.

Ammonia is, then, a compound substance, one of whose elements is hydrogen.

66. *Potassium removes Nitrogen from Ammonia.*—Fill a tolerably large bottle (Figure 37) partly full of strong

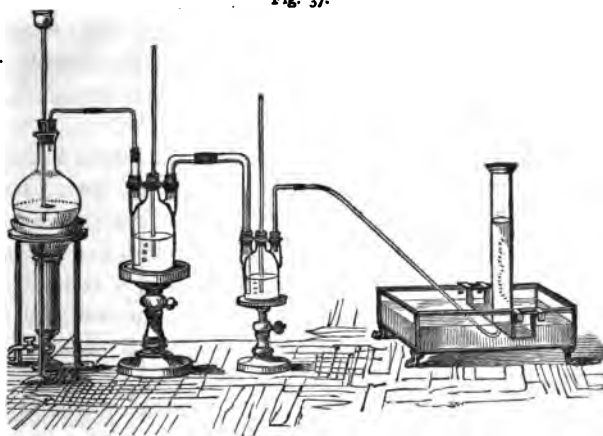
ammonia, and close it with a cork through which pass two

Fig. 36.



tubes, one reaching to the bottom of the bottle, and the

Fig. 37.



other passing through the cork. Let a stream of chlorine pass through the first tube. As it enters the ammonia,

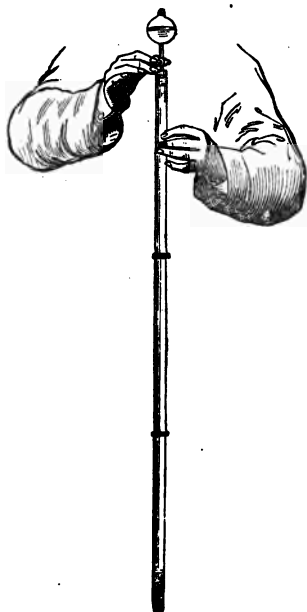
flashes of light are seen, and other indications of energetic action. The gas which escapes from the bottle through the other tube is passed through a bottle filled with water (called a *wash-bottle*), and is then collected in jars. This gas is evidently not ammonia, for it was not absorbed by the water. It is not chlorine, for it is colorless. It is not hydrogen or oxygen, for it neither burns when a lighted taper is applied to it, nor will a lighted taper burn in it. It does not affect either blue or red litmus-paper. It cannot be decomposed, and must therefore be regarded as an element.

It is called *nitrogen*, and its symbol is N.

67. *Is there any other Element in Ammonia?*—Hydrogen and nitrogen cannot be made to combine directly. We cannot therefore employ this method to determine whether ammonia gas contains more than these two elements. But if a gramme of ammonia gas be decomposed into hydrogen and nitrogen, the weight of the hydrogen and nitrogen together will be just one gramme. Hence it is clear that there is nothing but these two elements in ammonia.

68. *How much of each of these Elements in Ammonia?*—Let a long tube (Figure 38), closed at one end and divided into three equal parts by marks on the side, be filled with chlorine,

Fig. 38.



and a dropping-tube (see Figure 39) filled with ammonia be connected with it by means of a rubber cork so as to form an air-tight joint. If now the ammonia be allowed to drop slowly into the tube, the chlorine will decompose it, uniting with the hydrogen and setting the nitrogen free. After enough ammonia has passed in to fill the tube to the depth of about half an inch, allow dilute sulphuric acid to pass into the tube by means of the dropping-tube as long as it will. It will fill the tube just two thirds full. The other third will be filled with a gas which is found on trial to be nitrogen.

Fig. 39.



While this nitrogen has been set free, how much hydrogen has been taken away? The chlorine combines with the hydrogen to form muriatic acid. In this acid there are equal measures of hydrogen and chlorine. As the tube was full of chlorine at first, enough hydrogen to fill the tube must have been taken from the ammonia. By measure, then, there are three parts of hydrogen and one of nitrogen in ammonia.

Nitrogen weighs 14 times as much as the same bulk of hydrogen. Hence by weight there are in ammonia 3 parts of hydrogen to 14 parts of nitrogen.

69. *Hydrogen and Nitrogen condense one-half when they combine.* — To determine whether hydrogen and nitrogen undergo any change of volume when they combine, we must split up a measured quantity of ammonia into its constituents, and compare the space occupied by the ammonia before treatment with the space filled by its separated constituents. This we are enabled to do very easily, by availing ourselves of the tendency of ammonia to break up into its elements under the influence of a moderate heat.

The sealed limb of the U-tube is filled to about one third of its height with dry ammonia, over mercury, and

the height of the column of gas is accurately measured; care having been taken, as usual, to bring the mercury in each limb of the tube to a uniform level. Electric sparks are now made to pass between the platinum points, and the volume of the gas is immediately observed to increase. This dilatation continues for some five or ten minutes; and, when it ceases, the level of the mercury is to be made uniform again in both limbs of the tube. We now perceive that the original volume of gas has become doubled. If a little of the gas be allowed to escape from the tube, it is found to have lost its pungent odor, while the presence of hydrogen is indicated by the usual test.

This experiment proves that hydrogen and nitrogen, as combined in ammonia, occupy only half the space they fill in their free state; or, in other words, that 4 volumes of the mixed gases (3 volumes of hydrogen and 1 volume of nitrogen) condense to form 2 volumes of ammonia.

70. *Atomic Constitution of Ammonia.*—Hence in ammonia gas there are twice as many molecules as there would be in the nitrogen it contains, were it in a free state. Each of these nitrogen molecules, then, must be divided into two parts, or atoms, one of which is found in every molecule of ammonia. But there are three times as many molecules of hydrogen in ammonia as of nitrogen, and therefore three times as many atoms. Hence each molecule of ammonia contains three atoms of hydrogen, and its symbol will be H_3N .

MOLECULAR AND ATOMIC WEIGHTS.

71. *Molecular Weight.*—We can readily find the *molecular weight* (that is, *the relative weight of their molecules*) of all those substances which can by heat be converted into true gases, by weighing equal volumes of these gases under the same pressure and temperature.

There are, however, many substances which cannot be brought into a gaseous state. To determine the molecular weights of these substances, we must find their atomic constitution, and the atomic weights of their elements. Suppose, for instance, that we do not know the molecular weight of *water*, but do know that a molecule of water contains two atoms of hydrogen and one of oxygen, and that the atom of hydrogen weighs 1 and the atom of oxygen 16. The molecular weight of water must then be $16 + 2$ or 18.

In finding the molecular weight of different substances, they are all compared with *hydrogen*, whose molecular weight is assumed to be 2. The following table gives the molecular weights of several gases,* all of which contain hydrogen; also the relative weight of the hydrogen in each molecule:—

	Molecular Weight.	Weight of Hydrogen.		Molecular Weight.	Weight of Hydrogen.
H	2	—	H ₂ S	34	2
HCl	36.5	1	H ₃ N	17	3
HBr	81	1	H ₃ P	34	3
HI	128	1	H ₃ As	78	3
H ₂ O	18	2	H ₄ C	16	4

72. Atomic Weights. — When any element forms a number of compounds which can be brought into the gaseous state, we find its atomic weight by *first finding the molecular weight of these compounds, and then analyzing these compounds, so as to find the weight of the common element in each molecule*, or, what amounts to the same thing, *in equal volumes of the gases*.

Thus, in the above table, it is found that when HCl is decomposed, it gives *half its own volume*, or, in other

* These gases will be described hereafter. Their *composition*, as indicated by their symbols, is all that is to be noted here.

words, *half its own number of molecules*, of hydrogen. Hence a molecule of HCl contains *half a molecule*, or *one part by weight*, of hydrogen. The same is found to be true of HBr and HI . *Water* gas is found on analysis to give *its own volume*, or, in other words, *its own number of molecules*, of hydrogen. Hence each molecule of water contains *a whole molecule*, or *two parts by weight*, of hydrogen. The same is found to be true of H_2S . Again, H_3N gives *one and a half its own volume* of hydrogen. A molecule of ammonia, then, contains *one and a half molecules*, or *three parts by weight*, of hydrogen. The same is true of H_3P and H_3As . Again, H_4C (marsh-gas) gives *twice its own volume* of H ; and each of its molecules must therefore contain *two molecules*, or *four parts by weight*, of H .

In this way, it is found that *one part by weight* is the smallest quantity of hydrogen found in a molecule of any of its compounds. Hence 1 is taken as the atomic weight of hydrogen; and since the molecular weight of hydrogen has been assumed as 2, each of its molecules must contain 2 atoms.

In a similar way, it has been found that the molecular weight of nitrogen is 28, and its atomic weight 14. "This method of investigation can be extended to a large number of the chemical elements, and the conclusions to which it leads are evidently legitimate, and cannot be set aside until it can be shown that some substance exists whose molecule contains a smaller mass of any element than that hitherto assumed as the atomic weight, or, in other words, until the old atom has been divided."*

This method, however, is applicable only to those elements which form a number of gaseous or volatile compounds. In other cases, the number of atoms in a mole-

* Cooke's *First Principles of Chemical Philosophy*. All the quotations in this chapter and the next are from the same work.

cule is a matter of inference merely. Whenever analogous elements, as iodine, bromine, fluorine, and chlorine, combine with the same element, we infer that the molecules formed have the same atomic constitution, especially if the compounds have the same crystalline form and similar chemical relations. Of course, if we know the atomic *constitution* of a compound, and the atomic *weight* of one of its elements, we can find the atomic weight of its other element.

Suppose, for instance, we know that the molecule of *baric chloride* contains one atom of barium and two of chlorine, and that the atomic weight of chlorine is 35.5. We find on analysis that baric chloride contains 137 parts by weight of barium to 71 of chlorine. $71 = 35.5 \times 2 =$ the weight of two atoms of chlorine; hence the weight of the one atom of barium must be 137.

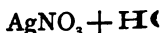
"Nevertheless, it is true in very many cases that our conclusion in regard to the number of atoms which a molecule may contain is more or less hypothetical, and hence liable to error and subject to change. This uncertainty, moreover, must extend to the atomic weights of the elements, so far as they rest on such hypothetical conclusions."

Experiment, however, has shown that it is *generally* true that the elementary atoms have the same *specific heat*; that is, if we take of different elements quantities proportionate to their atomic weights, and which therefore contain the same number of atoms, *the same amount of heat will raise them all the same number of degrees in temperature*; in other words, it takes just as much heat to raise 1 atom of hydrogen 1 degree in temperature as it does to raise 1 atom of nitrogen, oxygen, or any other element 1 degree.

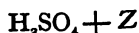
Hence, when we are in doubt as to the atomic weight of any element, we can sometimes settle the question by its *specific heat*.

QUANTIVALEN

73. *Quantivalence.* — 1
 ments replace one another
 found that while in some
 replace 1 of another, in
 or 4 atoms of another.
 argentic nitrate act upon
 change :—

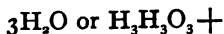


Here 1 atom of Ag changes
 When zinc acts upon sulfuric



Here 1 atom of Zn replaces
 of H.

Again, in the reaction of
 chloride, we have—



Here 1 atom of P replaces
 atoms of H.

“This relation of the elements to each other is called by Hofmann *quantivalence*; and selecting here, as in the system of atomic weights, the hydrogen atom as our standard of inference, the atoms of different elements are called *univalent*, *bivalent*, *trivalent*, or *quadrivalent*, according as they are, in the sense already indicated, *equivalent* to 1, 2, 3, or 4 atoms of hydrogen. These terms are very appropriate, since they are all derived from the same root as our common English word *equivalent*, which

best expresses the fundamental idea which underlies the whole subject."

Univalents are also called *monads*; bivalents, *dyads*; trivalents, *triads*; quadrivalents, *tetrads*; quinquivalents, *pentads*; and sexivalents, *hexads*.

All above the univalents or monads are often called *multivalents* or *polyads*.

Elements of even equivalency are called *artiads*, from a Greek word meaning *even*; and those of uneven equivalency *perissads*, from a Greek word for *uneven*.

It is necessary to distinguish carefully between the *intensity* of an atom's affinity and its *combining capacity*.

Thus Cl has a very intense affinity, but its combining capacity is only *one*; while Pt has a combining capacity of *six*, but a very weak affinity.

The difference of equivalency or combining capacity is often denoted by placing dashes or Roman numerals to the right of the symbol, as O^{II}, B^{III}, C^{IV}, N^V, S^{VI}.

The combining capacities of an atom may be designated as its *affinities*, and these affinities may be represented by dashes or dots, according as they are satisfied or not in combination. For example, the monad atoms of hydrogen and chlorine when separate may be represented thus, H· and Cl·; and when united thus, H-Cl. Again the dyad oxygen and the tetrad carbon may be represented thus, O: and C::; and the compounds water and marsh gas thus, H₂-O and C≡H₄. The dashes serve to connect the affinities of the elements that have combined, and to show how they are satisfied. Such symbols, designed to show the relations between the atoms, and, to a certain extent, the structure of the molecule, are called *graphic symbols* or *constitutional formulæ*. Several graphic methods have been devised, but the one here used, which is a combination of portions of the graphic methods of Cooke and Kékulé, is perhaps as simple and as clear as any.

It will be seen that, in the compounds muriatic acid, water, and marsh gas, all the affinities of both elements are satisfied. The same is true of carbonic anhydride, $C\equiv O_2$, and sulphuric anhydride, $S\equiv O_2$, sulphur being a hexad. But in carbonic oxide, $:C=O$, and sulphurous anhydride, $:S\equiv O_2$, two of the affinities remain unsatisfied. The same is true in ammonia, $H_3\equiv N$; since nitrogen is a pentad. The compounds of the former set are said to be *saturated*; those of the latter, *unsaturated*.

74. *Variation of Equivalency and Elementary Radicals.*—In many cases the remaining affinities of the unsaturated molecule are active, and one other dyad, or two other monad atoms, may be readily taken up. Thus $:C=O$ readily takes up one atom of oxygen, becoming $O=C=O$, or CO_2 , or two atoms of chlorine, becoming $Cl_2=C=O$, or $COCl_2$. In other cases, as with $:S\equiv O_2$ and $H_3\equiv N$, the remaining affinities are dormant, and are aroused to activity only under peculiar conditions. Those of $H_3\equiv N$ are developed only when ammonia is brought in contact with water or an acid. In the latter case they are suddenly awakened. Thus ammonia and muriatic acid instantly combine, forming the saturated molecule of sal ammoniac, $H_4\equiv N-Cl$.

Thus nitrogen, which is really a pentad, ordinarily appears as a triad; and sulphur, which is a hexad, appears as a dyad. The same is true of many other elements. This apparent change in the atomicities of certain elements is not easily accounted for. It is a remarkable fact that it almost always takes place by pairs of affinities. And it is not reasonable to suppose that there is any real change, but only that, under certain conditions, one or more pairs of the affinities of an atom may remain dormant.

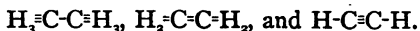
It would seem that the affinities of the different atoms which unite and satisfy each other are in opposite polar conditions, and that under certain circumstances pairs of affinities of the same atom, being in opposite polar condi-

tions, may be directed towards, and thus satisfy, each other, till directed elsewhere by some preponderating influence. The disposition of the affinities to remain dormant only in pairs explains why the perissad atoms cannot exist in a free state without entering into combination with each other to form molecules, while on the other hand artiad atoms may remain thus free. Thus we have H-H, hydrogen, and K-K, potassium, but Hg_2 , the dyad mercury. The monad atoms must, of course, always unite in pairs, and a molecule of such an element contains two atoms. But this is not the case with the *polyad* atoms. Thus a molecule of ordinary oxygen is $\text{O}=\text{O}$, but a molecule of ozone, an allotropic form of oxygen, is probably $\begin{smallmatrix} \text{O}-\text{O} \\ \diagup \quad \diagdown \\ \text{O} \end{smallmatrix}$. Again, a molecule of nitrogen is $:\text{N} \equiv \text{N}:$, with four dormant affinities; but a molecule of the allied pentad phosphorus is probably $\begin{smallmatrix} \text{P} \equiv \text{P} \\ | \quad | \\ \text{P} \equiv \text{P} \end{smallmatrix}$, or $\text{P}_2 \equiv \text{P}_2$.

We have seen, in the case of nitrogen, that elementary atoms of the same kind may unite by a part of their affinities only. This disposition is also manifested by certain other elements, but only when the remaining affinities of the atoms are satisfied by other atoms. Thus the dyad metals, copper and mercury, each form two chlorides $\text{Cu}=\text{Cl}_2$, $\begin{smallmatrix} \text{Cu} \\ | \\ \text{Cu} \end{smallmatrix} > \text{Cl}_2$, and $\text{Hg}=\text{Cl}_2$, $\begin{smallmatrix} \text{Hg} \\ | \\ \text{Hg} \end{smallmatrix} > \text{Cl}_2$. When atoms of the same kind unite in this way, they form what may be called *elementary radicals*. Such radicals are often enclosed in brackets thus, $[\text{Cu}_2]$, and $[\text{Hg}_2]$, and their compounds are written thus: $[\text{Cu}_2]=\text{Cl}_2$, $[\text{Cu}_2]=\text{O}$, $[\text{Hg}_2]=\text{Cl}_2$, and $[\text{Hg}_2]=\text{O}$. It will be seen that, when dyad atoms unite in this way, the atomicity of the radicals formed is the same as that of the original atom. The dyads oxygen and sulphur show a tendency to unite in this way to a still higher degree. Thus we have five sulphides of potassium, K-S-K, K-S-S-K, or

$K-[S_2]-K$, $K-[S_3]-K$, $K-[S_4]-K$, and $K-[S_5]-K$. It will be seen that any number of dyad atoms may be introduced into a radical in this way without changing the atomicity, since an atom, entering, satisfies one of the existing affinities and introduces another. When polyad atoms unite by a portion of their affinities, the atomicity of the radical is no longer the same as that of the original atom. For instance, two atoms of the tetrad iron unite thus, $:\text{Fe}-\text{Fe}:$, to form the hexad radical, $[\text{Fe}_2]::$, found in many of the compounds of iron, such as $[\text{Fe}_2]\equiv\text{Cl}_6$ and $[\text{Fe}_2]\equiv\text{O}_3$; and two atoms of the tetrad aluminium, thus, $:\text{Al}-\text{Al}:$, to form the hexad radical, $[\text{Al}_2]::$, found in all the compounds of this element, as $[\text{Al}_2]\equiv\text{Cl}_6$ and $[\text{Al}_2]\equiv\text{O}_3$.

But, of all the elements, the atoms of the tetrad carbon manifest the greatest disposition to unite with one another by a part of their affinities, especially when their remaining affinities are satisfied by atoms of hydrogen. For example, although C is a tetrad atom, the hydrocarbons, C_2H_6 , C_2H_4 , and C_2H_2 , are all saturated molecules, as shown by the following graphic symbols:—

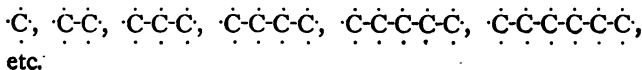


It is thus seen that two carbon atoms may unite by one, two, or three of the affinities of each, and thus give rise to hexad, tetrad, and dyad radicals.

Again, we have a well-known series of hydrocarbons, whose symbols are,

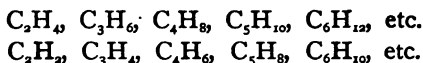


The structure of these molecules is shown by the following graphic symbols, the dashes indicating the affinities satisfied by the uniting of the carbon atoms with each other, and the dots the affinities remaining for the attachment of the hydrogen atoms:—

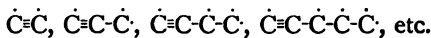
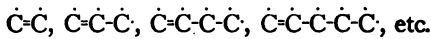


It will thus be seen at a glance why with each additional atom of C two of H are required ; that is, why each molecule of the above series differs from the last by the group of atoms CH_2 .

In a similar manner, each of the hydrocarbons, C_2H_4 and C_2H_2 , gives rise to a series, whose terms differ by CH_2 , and whose symbols are,



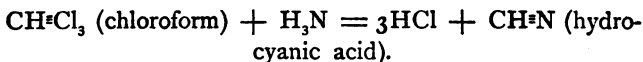
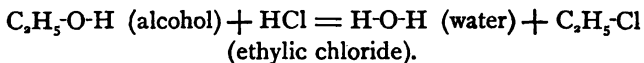
The structure of the molecules of these compounds is shown in the following symbols : —



As many as thirty atoms of carbon may thus be introduced into a molecule ; and as any one of the atoms introduced may unite with another by one, two, or three of its affinities, and the hydrogen atoms may be partially replaced by other single atoms or groups of atoms, the possible carbon compounds are literally innumerable.

75. *Compound Radicals, and the Integrity of the Molecule.*

— For every atom of hydrogen removed from any of the above series of hydrocarbons, there will remain one combining affinity unsatisfied. Thus we should have, $\cdot\text{C} \equiv \text{H}_3$, $:\text{C} = \text{H}_2$, $:\text{C} - \text{H}$, and $:\text{C} :$; and $\cdot\text{C}_2 \equiv \text{H}_3$, $:\text{C}_2 \equiv \text{H}_4$, $:\text{C}_2 = \text{H}_3$, $:\text{C}_2 = \text{H}_2$, etc. Many of these unsaturated groups of atoms play in compounds the part of elementary atoms. Thus, the graphic symbol of water is $\text{H} - \text{O} - \text{H}$, and that of alcohol $\text{C}_2\text{H}_5 - \text{O} - \text{H}$, the monad group C_2H_5 taking the place of the monad atom H. In methylic chloride, $\text{CH}_3 - \text{Cl}$, the monad group CH_3 takes the place of H in $\text{H} - \text{Cl}$; and in hydrocyanic acid, $\text{CH} \equiv \text{N}$, the triad group CH takes the place of H_3 in $\text{H}_3 - \text{N}$. Again, in chemical reaction these groups replace each other. Thus : —



These unsaturated molecules are called *compound radicals*. Their atomicity is the number of their unsatisfied affinities, and they are artiad or perissad according as this number is *even* or *odd*.

The hydrocarbon radicals are the most numerous and important, but many others exist.

The molecule of *water*, H_2O , by losing an atom of hydrogen, is converted into the univalent radical HO , which may be substituted in combination for one atom of hydrogen or other monads. Thus, water itself may be regarded as H.HO , analogous to muriatic acid, HCl .

Again, the saturated molecule $\text{S}\equiv\text{O}_3$ may lose one atom of oxygen and be converted into the dyad radical $\text{:S}\equiv\text{O}_2$, and the saturated molecule N_2O_3 , or $\text{O}_2\equiv\text{N-O-N}\equiv\text{O}_2$, may lose one atom of oxygen and break up into two molecules of the monad radical $\text{N}\equiv\text{O}_2$.

It must be distinctly understood that these compound radicals do not necessarily exist in the separate state ; and that those of uneven equivalency, unless, perchance, they contain the remarkable atom N , cannot exist in that state, their molecules, if liberated from combination with others, always doubling themselves, as we have seen to be the case with most of the elementary bodies. Thus HO , or H-O , is not known in the free state, the actually existing compound containing the same proportions of hydrogen and oxygen being H_2O_2 , or H-O-O-H . So also $\text{C}\equiv\text{H}_3$ is unknown in the free state, two of these groups of atoms at once combining to form $\text{H}_3\equiv\text{C-C}\equiv\text{H}_3$, or C_2H_6 .

Again, "the graphic symbols illustrate another theoretical principle, which, though almost self-evident, might be

overlooked if not dwelt upon especially ; namely, that on the multivalence of one or more of its atoms depends the integrity of every complex molecule. According to our present theories, no molecule can exist as an integral unit unless its parts are all bound together by such atomic clamps."

A molecule which contains only monad atoms can never contain more than two atoms. Thus we have H-H, H-Cl, and K-Cl, and we can fasten no monad atom to any of these molecules ; but by means of the pentad atom N we can fasten three other monad atoms to the molecule H-Cl, and form the complex molecule $H_4\equiv N-Cl$.

The carbon atoms have, as already illustrated, the most remarkable power to solder together atoms and radicals into complex molecules. The molecules of some of its compounds contain hundreds of atoms.

CLASSIFICATION OF ELEMENTS.

76. *Substitution.* — "When cotton-wool is dipped in strong nitric acid (rendered still more active by being mixed with twice its volume of concentrated sulphuric acid), and afterwards washed and dried, it is rendered highly explosive ; and, although no important change has taken place in its outward aspect, it is found on analysis to have lost a certain amount of hydrogen, and to have gained from the nitric acid an equivalent amount of nitric peroxide, NO_2 , in its place."

$C_{12}H_{20}O_{10}$ (cotton) becomes $C_{12}H_{14}(NO_2)_6O_{10}$ (gun-cotton).

Under the same conditions, glycerine undergoes a like change, and is converted into the explosive nitro-glycerine.

$C_6H_{16}O_6$ (glycerine)

becomes

$C_6H_{10}(NO_2)_6O_6$ (nitro-glycerine).

So also the hydro-carbon naphtha, called *benzole*, is changed into nitro-benzole.

C_6H_6 (benzole) becomes $C_6H_5(NO_2)$ (nitro-benzole).

This substitution does not materially alter the outward aspect of the compound. "Every one knows how closely gun-cotton resembles cotton-wool. In like manner, nitro-glycerine is an oily liquid, like glycerine; and nitro-benzole, although darker in color, is a highly aromatic, volatile fluid, like benzole itself. Products like these are called *substitution products*; and they certainly suggest the idea that each chemical compound has a certain definite structure, which may be preserved even when the materials of which it is built are, in part, at least changed. If, in the place of firm iron girders, we insert weak wooden beams, a building, while retaining all its outward aspects, may be rendered wholly insecure. And so the explosive nature of the products we have been considering is not at all incompatible with a close resemblance, in outward aspects and internal structure, to the compounds from which they are derived."

77. *Isomorphism*. — Closely associated with the facts of the last section are the phenomena of *isomorphism* (48).

If we examine the symbols of several isomorphous compounds, as $CaCO_3$, $MgCO_3$, $FeCO_3$, and $MnCO_3$, we shall see that they differ from each other only in the fact that one elementary atom has been replaced by another. It is not, however, every elementary atom which can thus be put in without altering the form. "This is a peculiarity which is confined to certain groups of elements, which for this reason are called *groups of isomorphous elements*. Moreover, as a rule, there is a close resemblance between the members of any one of these groups in all their other chemical relations. These facts, like those of the last section, tend to show that the molecules of every substance have a

determinate structure, which admits of a limited substitution of parts without undergoing essential change, but which is either destroyed or takes a new shape when, in place of one of its constituents, we force in an unconformable element."

78. *Isomerism, Allotropism, and Polymorphism.* — The same atoms may be grouped together in different ways, so as to form different molecules, which present essentially distinct qualities. Hence distinct substances may have the same composition; and they are then said to be *isomeric*, and the phenomenon is called *isomerism*. Thus, common *sugar* and *gum arabic* have exactly the same composition, $C_{12}H_{22}O_{11}$, and are *isomeric*.

When, however, the differences are not sufficiently great to justify a distinct name, the two bodies are said to be different *allotropic* states of the same substance, and the phenomenon is called *allotropism*. Thus, there are three varieties of *tartaric acid* which differ in their action on polarized light, but which are in almost every other respect identical.

Sometimes a substance *crystallizes* in fundamentally different forms, as calcic carbonate in the minerals *calcite* and *aragonite*. This phenomenon is called *polymorphism*, and is invariably accompanied by a marked difference of properties.

Differences of this kind, even more marked, are found among elementary substances, and give strong grounds for believing that these elements may be really composite.

79. *Electrical Relations of the Elements.* — When the electric current is passed through any compound liquid which is a conductor of electricity, the liquid is decomposed; its atoms, or radicals, travelling in opposite directions towards the two poles. Thus, when the current is sent through muriatic acid, the hydrogen atoms go towards the negative pole, or *cathode*, and the chlorine atoms towards

the positive pole, or *anode*. There are certain elements and radicals which, like hydrogen, always go towards the negative pole; and certain others, like chlorine, which always go toward the positive pole. The former are called *electro-positive*, and the latter *electro-negative* elements. There are other elements which in some of their compounds are electro-positive, while in others they are electro-negative. The electrical relations of the elements are best shown by grouping the elements in series, so that each member of the series shall be electro-positive when in combination with the elements which follow it, and electro-negative when combined with those which precede it. It is found that the non-metals are always negative when combined with the metals, which are then positive. The electrical relations of the metals show that *hydrogen*, although a gas, and the lightest substance known, is really a *metal*. It is the one gaseous metal, as mercury is the one liquid metal.

80. *The Metals*. — "The characteristic qualities of a metal, with which every one is more or less familiar, are the so-called metallic lustre, that peculiar adaptability of molecular structure known as malleability or ductility, and the power of conducting electricity or heat. These qualities are found united and in their perfection only in the true metals, although one, or even two of them, are well developed in several elementary substances, which, on account of their chemical qualities, are now almost invariably classed among the non-metals; as, for example, selenium, tellurium, arsenic, antimony, boron, and silicon."

81. *Scheme of Classification*. — The classification of the elementary atoms which has been adopted in this book is shown in the following table:—

TABLE.

The elements marked with a * are *non-metals*; all the others are *metals*. The names of the rarer elements are in *italics*.

PERISSAD ELEMENTS.	Atomic Weights.	Symbols.	Quantita- lence.	ARTIAD ELEMENTS.	Atomic Weights.	Symbols.	Quantita- lence.
Hydrogen	1.0	<i>H</i>	I	Copper	63.4	<i>Cu</i>	II
Fluorine*	19.0	<i>F</i>	"	Mercury	200.0	<i>Hg</i>	"
Chlorine*	35.5	<i>Cl</i>	"	Calcium	40.0	<i>Ca</i>	"
Bromine*	80.0	<i>Br</i>	"	Strontium	87.6	<i>Sr</i>	"
Iodine*	127.0	<i>I</i>	"	Barium	137.0	<i>Ba</i>	"
<i>Lithium</i>	7.0	<i>Li</i>	"	Lead	207.0	<i>Pb</i>	"
Sodium	23.0	<i>Na</i>	"	Magnesium	24.0	<i>Mg</i>	"
Potassium	39.1	<i>K</i>	"	Zinc	65.2	<i>Zn</i>	"
<i>Rubidium</i>	85.4	<i>Rb</i>	"	<i>Indium</i>	72.0	<i>In</i>	"
<i>Cesium</i>	133.0	<i>Cs</i>	"	Cadmium	112.0	<i>Cd</i>	"
Silver	108.0	<i>Ag</i>	"	<i>Glucinum</i>	9.3	<i>G</i>	"
<i>Thallium</i>	204.0	<i>Tl</i>	I or III	<i>Yttrium</i>	61.7	<i>Y</i>	"
Gold	197.0	<i>Au</i>	III	<i>Erbium</i>	112.6	<i>E</i>	"
Boron*	11.0	<i>B</i>	"	<i>Cerium</i>	92.0	<i>Ce</i>	"
Nitrogen*	14.0	<i>N</i>	III or V	<i>Lanthanum</i>	93.6	<i>La</i>	"
Phosphorus*	31.0	<i>P</i>	"	<i>Didymium</i>	95.0	<i>D</i>	"
Arsenic*	75.0	<i>As</i>	"	Nickel	58.8	<i>Ni</i>	"
Antimony*	122.0	<i>Sb</i>	"	Cobalt	58.8	<i>Co</i>	"
Bismuth*	210.0	<i>Bi</i>	"	Manganese	55.0	<i>Mn</i>	II or IV
<i>Vanadium</i>	51.37	<i>V</i>	"	Iron	56.0	<i>Fe</i>	"
Uranium	120.0	<i>U</i>	"	Aluminium	27.4	<i>Al</i>	"
<i>Columbium</i>	94.0	<i>Cb</i>	V	Chromium	52.2	<i>Cr</i>	"
<i>Tantalum</i>	182.0	<i>Ta</i>	"	<i>Ruthenium</i>	104.4	<i>Ru</i>	"
				<i>Osmium</i>	199.2	<i>Os</i>	"
				<i>Rhodium</i>	104.4	<i>R</i>	"
				<i>Iridium</i>	196.0	<i>Ir</i>	"
				<i>Palladium</i>	106.6	<i>Pd</i>	"
				Platinum	197.4	<i>Pt</i>	"
				Titanium	50.0	<i>Ti</i>	"
				Tin	118.0	<i>Sn</i>	"
				<i>Zirconium</i>	89.6	<i>Zr</i>	IV
				<i>Thorium</i>	231.4	<i>Th</i>	"
				Silicon*	28.0	<i>Si</i>	"
				Carbon*	12.0	<i>C</i>	"
ARTIAD ELEMENTS.							
Oxygen*	16.0	<i>O</i>	II				
Sulphur*	32.0	<i>S</i>	II or VI				
<i>Selenium*</i>	79.4	<i>Se</i>	"				
<i>Tellurium*</i>	128.0	<i>Te</i>	"				
<i>Molybdenum</i>	96.0	<i>Mo</i>	VI				
Tungsten	184.0	<i>W</i>	"				

"In the first place, the atoms are divided into two large families, the *Perissads* and the *Artiads* (see section 73, page 67).

"In the second place, these families are subdivided into groups (separated by bars in the table) of closely allied elements. The atoms of any one of these groups are *isomorphous*, and they are arranged in the order of their weights, which is found to correspond also, in almost every case, with their electrical relations. Each group forms a very limited chemical series; and not only the weights and the electrical relations of the atoms, but also many of the physical qualities of the elementary substances vary regularly as we pass from one end of the series to the other. The order of the variation, however, is not always the same; for while, in some cases, the lightest atoms of a series are the most electro-negative, in other cases they are the most electro-positive."

82. *Types of Chemical Compounds.* — There are three modes of atomic grouping to which so large a number of substances may be referred, that they are regarded as molecular types or patterns. Hydrogen, water, and ammonia, HH , H_2O , and H_3N are generally taken as the representatives of these types; and substances are said to belong to the *type of hydrogen*, to the *type of water*, or to the *type of ammonia*, as the case may be. In the first of these types a single univalent atom or radical is united to another single univalent atom; in the second, a bivalent atom binds together two univalent atoms, or their equivalents; in the third a trivalent atom binds together three univalent atoms, or their equivalents.

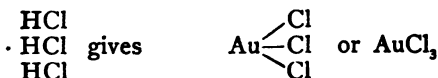
83. *Condensed Types.* — "In the same way that a bivalent atom may bind together two univalent atoms or their equivalents, so also it may serve to bind together two *molecules*; and, in like manner, a trivalent atom may bind together three *molecules* into a more complex molecular

group; and thus are formed what are called *condensed types*."

Thus two molecules of muriatic acid may be bound together by a bivalent atom of calcium, which replaces the H from both molecules.



Also 3 molecules of HCl may be bound together by a trivalent atom of gold.



Most of the inorganic compounds may be regarded as belonging to the first two types with or without condensation.

THE WATER TYPE.

84. *Bases and Acids*. — One of the hydrogen atoms of water seems to be more readily replaced by a metal than the other, though both may be replaced by a positive element or radical, and also by a negative element or radical. It is, therefore, often simpler to regard the typical molecule of water as *hydric hydrate*, HHO; that is, as a positive atom of hydrogen combined with the negative radical HO, or *hydroxyl*. The first H may be regarded as the atom most readily replaceable by a metal or positive radical, and the second as the one most readily replaceable by a non-metal or negative radical. On replacing the first or positive H by a positive element or radical, we get a compound called a *base*; and on replacing the H of the hydroxyl by a negative element or radical, we get a compound called an *acid*. Thus, KHO, *potassic hydrate*, and Ca(HO)₂, *calcic hydrate*, are *bases*; and

$\text{H}(\text{NO}_2)'\text{O} = \text{HNO}_2$, *hydric nitrate*, and $\text{H}_2(\text{SO}_2)''\text{O}_2 = \text{H}_2\text{SO}_4$, *hydric sulphate*, are *acids*.

This substitution of a negative element or radical in the place of the hydrogen of the hydroxyl gives rise to a new negative radical of the same degree of equivalence as that of the element or radical substituted. Thus NO_2 is univalent, and SO_4 bivalent.

Most of the acids are very corrosive substances, and have the characteristic property of changing blue litmus solution or paper to red. The bases, known as *potassic*, *sodic*, and *ammonic hydrates*, are also very corrosive, but they have the property of turning red litmus to blue. These bases are called *alkalies*. The bases have generally the property of neutralizing acids.

85. *Salts*.—When the positive H is replaced by a metal or positive radical, and the H of the hydroxyl by a non-metal or negative radical, the compound formed is called a *salt*. Of course, this replacement may occur at separate stages; and a salt may be formed by the replacement of the hydrogen of a base by a non-metal or negative radical, or by the replacement of the hydrogen of an acid by a metal or positive radical. Thus $\text{K}(\text{NO}_2)'\text{O} = \text{KNO}_2$, *potassic nitrate*, and CaSO_4 , *calcic sulphate*, are *salts*.

It will be noticed that each of the above compounds contains three elements, and they are therefore sometimes called *ternary* compounds.

86. *The Names of Bases, Acids, and Salts*.—The name of each of the above compounds is derived from the name *hydric hydrate* by the substitution of the name of the new element introduced instead of that of the element replaced. Thus, when a metal takes the place of the first H in hydric hydrate, HHO , its Latin name with the ending *-ic* takes the place of the *hydric* in the name of the original compound. Thus AgHO is *argentic hydrate* and KHO *potassic hydrate*. When the metal substituted has two degrees of equiva-

lency, the lower degree is indicated by the ending *-ous*. Thus $\text{Fe}''(\text{HO})_2$ is *ferrous hydrate*, and $\text{Fe}_2'''(\text{HO})_3$ is *ferric hydrate*.

When a non-metal, either alone or joined with oxygen, takes the place of the H in the hydroxyl, the first part of the name of that non-metal takes the place of *hydr-* in *hydrate*. Thus $\text{H}(\text{NO}_2)\text{O} = \text{HNO}_3$ is called *hydric nitrate*. When the new negative radical formed by the substitution of the same negative element has two degrees of oxidation, the lower degree is indicated by the ending *-ite*. Thus $\text{H}(\text{NO})'\text{O} = \text{HNO}_2$ is *hydric nitrite*, and $\text{H}(\text{NO}_2)'\text{O}^* = \text{HNO}_3$ is *hydric nitrate*. When it has more than two degrees of oxidation, a lower degree is expressed by the prefix *hypo-*, and a higher degree by *per-* or *hyper-*. Thus

HClO is hydric hypochlorite
 KClO " potassic "
 HClO_2 " hydric chlorite
 KClO_2 " potassic "
 HClO_3 " hydric chlorate
 HClO_4 " " hyperchlorate.

When a new negative and a new positive element are introduced into HHO , so as to form a *salt*, a corresponding change is made in the name.

KNO_3 is potassic nitrate
 KNO_2 " " nitrite
 KClO_3 " potassic chlorate
 KClO_4 " " hyperchlorate.

87. *Kinds of Salts.* — The acid H_2SO_4 , *hydric sulphate*, has two atoms of H to be replaced by a metal. Such acids are said to be *dibasic*, and they may give rise to *mono-metallic* or *acid salts*, to *di-metallic* or *neutral salts*, or to *double*

* It will be remembered that N is both trivalent and quinquivalent.

salts, according as one or both atoms of H are replaced by a metal, or as they are replaced by different metals. Thus,

HNaSO_4 is acid sodic sulphate
 Na_2SO_4 " neutral sodic sulphate
 $\text{K}_2''\text{Al}_2'''(\text{SO}_4)_4$ " potassio-aluminic sulphate (alum)

$\text{H}_3\text{PO}_4 = \text{H}_3(\text{PO})'''\text{O}_3$ is *tribasic*, since it has three atoms of replaceable hydrogen. Such acids may form *mono-metallic* salts, when *one* atom only of H is replaced by a metal; *bi-metallic* salts, when 2 atoms of H are replaced by a metal; *neutral* salts, when all the atoms of H are replaced by a metal; and *double* or *triple* salts, when the H atoms are replaced by *two* or *three* different metals.

Thus we have

H_3PO_4
 H_2NaPO_4
 HNa_2PO_4
 Na_3PO_4
 HKNaPO_4 , etc.

When a salt is formed by replacing a part of the H of a base by a negative element or radical, the salt is called a *basic* salt.

88. *Anhydrides*. — $\text{H}_2\text{SO}_4 - \text{H}_2\text{O} = \text{SO}_3$; and 2HNO_3 or $\text{H}_2\text{N}_2\text{O}_6 - \text{H}_2\text{O} = \text{N}_2\text{O}_5$. And so in general, when we abstract one or more molecules of water from an acid, there remains a *binary* compound. Such a compound is called an *acid oxide* or *anhydride*, and may be regarded as a molecule of water from which both atoms of H have been displaced by a negative element or radical.

H_2O , if both of the atoms of H are replaced by the bivalent radical SO_2 , becomes SO_2O , or SO_3 , *sulphuric anhydride*. If we replace both atoms of H by the univalent radical NO_2 , we get $(\text{NO}_2)_2\text{O}$, or N_2O_5 , *nitric anhydride*.

The names of the anhydrides take the ending *-ous* or *-ic*, according as the name of the acid from which they are

derived ends in *-ite* or *-ate*. Thus SO_2 (from *hydric sulphite*) is *sulphurous anhydride*; and N_2O_5 (from *hydric nitrate*) is *nitric anhydride*.

89. *Basic Oxides*.—If we abstract one or more molecules of water from a *base*, a compound remains which is called a *basic oxide*, and which may be regarded as a molecule of water in which the H is replaced by a metal. Thus $\text{CaH}_2\text{O}_2 - \text{H}_2\text{O} = \text{CaO}$, *calcic oxide*; 2KHO or $\text{K}_2\text{H}_2\text{O}_2 - \text{H}_2\text{O} = \text{K}_2\text{O}$, *potassic oxide*.

In the formation and naming of these compounds it is well to regard water, not as *hydric hydrate*, HHO , but as *hydric oxide*, H_2O . The name is then derived from *hydric oxide* in a manner similar to that already described. Thus

K_2O is potassic oxide.	|	$\text{Fe}''\text{O}$ is ferrous oxide.
Ag_2O " argentic "	|	$\text{Fe}_2''' \text{O}_3$ " ferric "

Sometimes other oxides besides these basic oxides are formed. In such cases, the number of atoms of oxygen in a molecule is generally indicated by the prefixes *di-* (two), *tri-* (three), *tetr-* (four), and *pent-* (five). Thus we have K_2O , *potassic oxide*; K_2O_2 , *potassic dioxide*; and K_2O_4 , *potassic tetroxide*.*

The basic oxides, when acted upon by acids, always give rise to salts and H_2O , the H of the acid changing place with the metal of the oxide.

THE HYDROGEN TYPE.

90. The typical molecule of hydrogen, HH , may be regarded as *hydric hydride*. From this name the names of all its derivative compounds are formed by a simple substitution of the name of the new element or elements

* The prefixes *proto-* and *sub-* are sometimes used to denote the *lowest oxide*, and *per-* to denote the *highest oxide*.

introduced. Thus HCl is *hydric chloride*; Cu_2H_2 , *cuprous hydride*; AgCl , *argentic chloride*; etc.

When the second or negative atom of H is replaced by a non-metal of the univalent or bivalent group, the compound formed is an *acid*. This acid is called a *hydracid* or *binary acid*, to distinguish it from the *oxyacids* or *ternary acids* already described.

These acids are

HCl ,	hydric	chloride.
HBr ,	"	bromide.
HF ,	"	fluoride.
HI ,	"	iodide.
H_2S ,	"	sulphide.
H_2Se ,	"	selenide.
H_2Te ,	"	telluride.

The first or positive atom in the HH is rarely replaceable by a metal until the negative atom has been replaced by a negative element, but it is readily replaceable by positive radicals, such as CH_3 (*methyl*), C_2H_5 (*ethyl*), etc. The compounds thus obtained are called *hydrides*. When one atom is replaced by a non-metal, and the positive atom by a metal or positive radical, the resulting compound is called a *salt*. These salts are sometimes called *binary salts*; and those which contain F , Cl , Br , or I , *haloid salts*. They may, of course, be formed by replacing the H of a hydracid by a metal, or the H of a hydride by a non-metal.*

THE AMMONIA TYPE.

91. Phosphorus, arsenic, and antimony form compounds with H by replacing the N in ammonia. Thus we have

* The number of atoms of Cl , Br , I , S , etc., in these binary compounds is often indicated by the prefixes used for oxides (89).

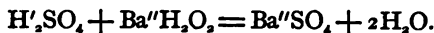
H_3N , ammonia.	H_3P , hydric phosphide.
H_3As , hydric arsenide.	H_3Sb , hydric antimonide.

In all these compounds the H may be replaced by Cl. Thus we have

NCl_3 , nitric chloride.	PCl_3 , phosphorous chloride.
AsCl_3 , arsenious "	SbCl_3 , antimonous "

DOUBLE DECOMPOSITION.

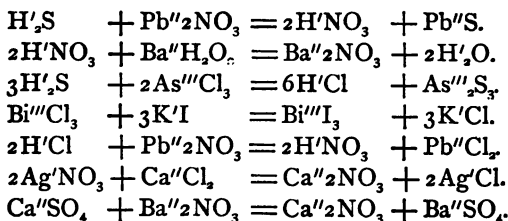
92. The salts, both binary and ternary, are ordinarily formed by a double transfer of elements, as shown in the following equation :—



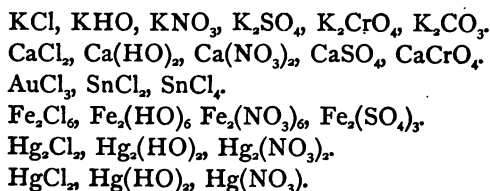
Such a double transfer of elements is called *double decomposition*. The change which takes place is usually called simply a *reaction*.

On mixing any two solutions, such a change will always take place, when an *insoluble* or *volatile* compound would thereby be formed.

In tracing out the following reactions, it must be borne in mind that it is always the *metals* which change places ; and that they must always be in equivalent quantities. It is better in all cases to indicate by the proper mark the combining power of the elements which are to replace each other. Before beginning to work the problems of the next section, the student should be able to read and explain all the equations given below, and especially to give the reason for the number of molecules used in each case. If more molecules than one are used in any case, it is always in order that the combining units of the elements which replace each other may be equal.



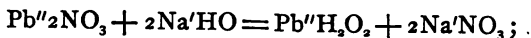
The following formulæ will enable the student to write all which are used in the problems :—



The salts of all univalent metals are like those of K ; those of bivalent metals (except Hg and Cu), like those of Ca. The two series of salts of Cu are like those of Hg. Mn, Cr, and Al, as quadrivalents, form salts like the quadrivalent Fe.

PROBLEMS.


1. Show the reaction between plumbic nitrate and sodic hydrate.



that is, plumbic nitrate *plus* sodic hydrate gives plumbic hydrate *plus* sodic nitrate.

2. Plumbic nitrate and hydric sulphate.
3. Cupric sulphate and potassic hydrate.
4. Manganic sulphate and sodic hydrate.
5. Zincic sulphate and potassic hydrate.
6. Cobaltic nitrate and sodic hydrate.
7. Manganic sulphate and ammoniac carbonate, $(\text{H}_4\text{N})_2\text{CO}_3$.

8. Baric nitrate and ammoniac carbonate.
9. Calcic sulphate and ammoniac carbonate.
10. Strontic nitrate and calcic sulphate.
11. Aluminic sulphate and ammoniac hydrate, $(H_4N)HO$.
12. Ferrous nitrate and ammoniac hydrate.
13. Hydric chloride and argentic nitrate.
14. Hydric chloride and plumbic nitrate.
15. Hydric chloride and mercurous nitrate.
16. Hydric sulphide and argentic nitrate.
17. Hydric sulphide and plumbic nitrate.
18. Hydric sulphide and mercurous nitrate.
19. Argentic nitrate and potassic iodide.
20. Potassic iodide and plumbic nitrate.
21. Potassic iodide and mercurous nitrate.
22. Stannous chloride and hydric sulphide.
23. Stannic chloride and hydric sulphide.
24. Bismuthic chloride and hydric sulphide.
25. Stannous chloride and potassic hydrate.
26. Auric chloride and hydric sulphide.
27. Mercuric chloride and hydric sulphide.
28. Platinic chloride and potassic iodide.
29. Auric chloride and potassic iodide.
30. Cupric sulphate and hydric sulphide.
31. Mercuric chloride and potassic iodide.
32. Cupric sulphate and potassic iodide.
33. Aluminic chloride and ammoniac hydrate.
34. Baric chloride and ammoniac carbonate.
35. Calcic chloride and ammoniac carbonate.
36. Baric chloride and sodic hydrate.
37. Strontic chloride and calcic sulphate.
38. Argentic nitrate and ammoniac hydrate.
39. Argentic nitrate and hydric sulphate,
40. Cadmic chloride and hydric sulphide.

 If additional problems are desired, they can be easily prepared by the teacher.

SUMMARY OF CHEMICAL ACTION.

An *element* is a substance that cannot be decomposed into anything simpler. 63 are now known.

A *compound* is made up of elements. (53.)

A *molecule* is the smallest mass of any substance that can exist in a free state.

An *atom* is the smallest mass that can exist in a molecule. (57.)

Affinity is the force that holds the elements in combination. It acts among atoms, while cohesion acts among molecules. (54.)

Water is made up of hydrogen and oxygen, each molecule containing 2 atoms of hydrogen and 1 of oxygen. (57, 58.)

Muriatic acid is made up of hydrogen and chlorine, each molecule containing 1 atom of hydrogen and 1 of chlorine. (64.)

Ammonia is made up of hydrogen and nitrogen, each molecule containing 3 atoms of hydrogen and 1 of nitrogen. (70.)

The *molecular weights* of substances are the relative weights of their molecules, that of the hydrogen molecule being taken as 2. (71.)

The *atomic weights* of the elements are the relative weights of their atoms, that of hydrogen being taken as 1. (72.)

Atoms differ not only in the *intensity* of their affinities, but also in their *combining capacities*.

The combining capacity of an atom is called its *quantivalence* or *atomicity*.

A *univalent* or *monad* element is one whose atom is capable of combining with 1 atom of hydrogen or chlorine.

A *bivalent* or *dyad* element is one whose atom is capable of combining with 2 atoms of hydrogen.

A *trivalent* or *triad* element is one whose atom is capable of combining with 3 atoms of hydrogen.

A *quadrivalent* or *tetrad* element is one whose atom is capable of combining with 4 atoms of hydrogen.

A *quivalent* or *pentad* element is one whose atom is capable of combining with 5 atoms of hydrogen.

A *sextivalent* or *hexad* element is one whose atom is capable of combining with 6 atoms of hydrogen.

Artiad elements are those of *even* equivalency ; that is, dyads, tetrads, and hexads.

Perissad elements are those of *uneven* equivalency ; that is, monads, triads, and pentads.

The structure of the molecules is often indicated by lines connecting the atoms and showing the way in which the combining units of the atoms are disposed of.

A *saturated* compound is one in which all the combining units of the atom are saturated.

A *non-saturated* compound is one in which only a part of the combining units of the atoms are saturated. (73.)

Affinity usually acts between atoms of different kinds, but sometimes between those of the same kind. (74.)

Compound radicals are unsaturated groups of atoms, the atomicity of the radical being equal to the number of unsaturated units in the group. (75.)

Substitution products are obtained by the replacement of a part of the atoms of a molecule by new atoms without destroying the molecular structure of the compound. (76.)

Isomorphous elements are those that can replace each other in compounds without altering their crystalline structure. (77.)

Isomeric substances are those which have the same composition, but different properties, owing to different groupings of the atoms in the molecule.

The *allotropic states* of a substance are probably due to the same cause, but the difference in properties is less marked than in isomeric substances. (78.)

The different elements are called *electro-positive* or *electro-negative*, according as they travel towards the negative or positive pole of the battery. (79.)

The more electro-positive elements are called *non-metals*, and the more electro-negative are called *metals*. These classes gradually shade off into each other. (80, 81.)

The elements are classified according to the *combining capacities*, the *electrical affinities*, and the *crystalline relations* of their atoms.

Water, *hydrogen*, and *ammonia* are taken as the representatives of the three most common types of chemical compounds. (82.)

These types are often *condensed*. (83.)

To the *water* type belong the ternary *bases*, *acids*, and *salts*, and the *basic oxides* and *anhydrides*. (84, 85.)

The names of the ternary *bases*, *acids*, and *salts* may be readily derived from *hydric hydrate*, one of the names of water.

Dibasic acids give rise to *acid*, *neutral*, and *double salts*; *tribasic acids*, to *mono-metallic*, *di-metallic*, *neutral*, *double*, and *triple salts*.

The *anhydrides* are named from their acids.

The names of the *basic oxides* may be derived from *hydric oxide*, another name of water. (84-89.)

To the *hydrogen* type belong the *hydracids* and the *binary* or *haloid salts*. (90.)

To the *ammonia* type belong certain compounds of nitrogen, phosphorus, arsenic, and antimony. (91.)

Salts are ordinarily formed by *double decomposition*. (92.)

NON-METALLIC ELEMENTS OR NON-METALS.

HYDROGEN.

93. *Its Classification.* — Hydrogen is the lightest substance known, and possesses nearly all the properties of a non-metal in such perfection that chemists have long hesitated to class it with the metals, though its chemical relations clearly show it to belong to that class of elements (79). It combines with nearly every non-metal, but with only two or three of the metals. Its compounds with Cl, O, and S are analogous to those of the same elements with the monad metals. It is readily replaced in its compounds by the metals, and most readily by the monad metals. But it is also readily replaced by the non-metallic elements and radicals, and in this respect resembles a non-metal.

It is on the whole most convenient to begin our description of the non-metals with that of the *quasi* non-metal hydrogen.*

* Graham has recently shown that palladium absorbs 800 or 900 times its own volume of hydrogen, its density being sensibly diminished. When a wire of palladium is charged with hydrogen by being made the negative pole of a battery, it increases in length and volume. Graham considers the hydrogen under the circumstances to be in the metallic state, and calls it *hydrogenium*. From his experiments with the alloy of hydrogen and palladium, it appears that hydrogenium is a solid white metal, of density about 2, magnetic, conducting electricity, and uniting with palladium in the proportion of 1 atom to 1 atom. The alloy possesses the properties of gaseous hydrogen intensified.

94. *Its Preparation.* — Hydrogen may be obtained for experimental purposes by deoxidizing water.

If a tube of iron or porcelain, containing a quantity of filings or turnings of iron, be fixed across a furnace, and its middle portion be made red-hot, and then the vapor of water transmitted over the heated metal, a large quantity of permanent gas will be disengaged from the tube, and the iron will become converted into oxide. The gas is hydrogen, and may be collected over water.*

* Gases which are not absorbed by water, or but slightly so, can be collected by first filling the vessel with water, and inverting it with its mouth under water. The tube through which the gas is escaping is introduced under the mouth of the jar, and the gas rises and fills the jar.

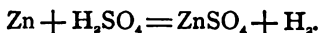
For collecting gases in this way, a *pneumatic trough* is useful and almost indispensable. This apparatus consists of a vessel deep enough to allow of filling and inverting under the water any of the jars ordinarily used. A shelf perforated with holes extends across the vessel about an inch under the surface of the water. After the jar is filled with water and inverted, it is set upon the shelf over one of the holes. The delivery tube (which, except the part passing through the cork, may be of rubber) is then passed into this hole, and the jar filled. It is convenient to have a shelf large enough to hold several jars, after they have been filled with gas.

The best pneumatic trough is made of soapstone or copper; but any vessel which will hold water, and has a perforated shelf, will answer the purpose. The teacher can easily provide himself with such a trough at little expense.

Gases are transferred from jar to jar with the utmost facility, by first filling with water the vessel which is to receive the gas, inverting it, carefully keeping its mouth under the water, and then bringing beneath it the aperture of the jar containing the gas. Gently incline the latter, and the gas passes into the second vessel. When the latter is narrow, a funnel may be placed loosely in its neck, by which loss of gas will be prevented.

A jar wholly or partially filled with gas at the pneumatic trough may be removed by placing under it a shallow basin, or a common plate, so as to carry away enough water to cover the edge of the jar: and many gases, especially oxygen, may thus be preserved for many hours.

Hydrogen is, however, more easily obtained by decomposing muriatic or dilute sulphuric acid with zinc, the metal then displacing the hydrogen in the manner indicated by the following equation :—



A wide-necked bottle is chosen, and fitted with a sound cork, perforated by two holes for the reception of a small

Gas-jars are often capped at the top, and fitted with a stop-cock for transferring gas to bladders or rubber bags. When such a vessel is to be filled with water, it may be slowly sunk in an upright position in the well of the pneumatic trough, the stop-cock being open to allow the air to escape, until the water reaches the brass cap. The cock is then to be turned, and the jar lifted upon the shelf, and filled with gas in the usual way.

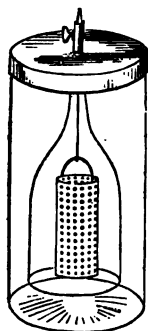
When a gas is much lighter or much heavier than atmospheric air, it may often be collected and examined without the aid of the pneumatic trough. A bottle or narrow jar may be filled with hydrogen by inverting it over the end of an upright tube delivering the gas. The air will soon be wholly displaced, and the vessel filled. If the mouth of the jar be wide, it must be partially closed by a piece of cardboard during the operation. This method of collecting gases by displacement is often extremely useful.

Gases, like ammonia and muriatic acid, which are absorbed by water, must be collected over mercury. An evaporating dish of Berlin porcelain answers every purpose of a mercury trough. One five inches in diameter is large enough to use with small jars. It should be set in a shallow dish of strong glass or earthenware, to prevent loss of mercury in case of accident. It should then be filled nearly full of mercury. The jar or cylinder to be used is next filled with mercury to the brim. A ground-glass cover is then placed on the mouth of the cylinder and held firmly with the right hand, the cylinder inverted, and its mouth plunged beneath the mercury in the evaporating dish. It is well to put the cylinder in a strong dish while filling and inverting it, to save any mercury which may be spilled. After the cylinder is filled and inverted over the mercury in the dish, the plate is slipped from its mouth, and the cylinder is securely fastened in the clamp of a retort-stand, so that its mouth is held about half an inch above the bottom of the dish.

tube-funnel, reaching nearly to the bottom of the bottle, and a piece of bent glass tube to convey away the disengaged gas. Granulated zinc, or scraps of the malleable metal, are put into the bottle, together with a little water, and sulphuric acid slowly added by the funnel, the point of which should dip into the liquid. The evolution of gas is easily regulated by the supply of acid; and when enough has been discharged to expel the air of the vessel, it may be collected over water. (See Figure 46, page 134.)

95. *The Hydrogen Generator.* — The most convenient apparatus for preparing hydrogen is the self-regulating generator shown in Figure 40. It consists of a glass

Fig. 40.



vessel closed with a metallic cap. A bell-shaped glass vessel, open at top and bottom, is fastened to this cap by an air-tight joint. A tube closed by a stop-cock passes through the cap into the bell-shaped vessel. A copper bucket perforated with fine holes is hung from a hook inside this vessel. This bucket is filled with shreds of sheet zinc or bits of granulated zinc. The outer vessel is filled about two thirds full of dilute sulphuric acid (the ordinary oil of vitriol diluted with about ten parts of water). The metallic cap, with the

bell-glass attached, is then put in its place, and the stop-cock opened. The air is first driven out, and the dilute acid coming in contact with the zinc begins to act upon it, and hydrogen is given off in abundance. When sufficient hydrogen has been obtained, the stop-cock is closed, the hydrogen generated collects in the upper part of the bell-glass, and drives the acid out. As soon as the acid is driven out, the action ceases until the stop-cock is opened again, and the hydrogen allowed to escape. By means of rubber tubing, the hydrogen can be conveyed from the

generator to the jar or vessel in which it is to be collected. Care must be taken that all the air is driven out of the apparatus before the gas is collected.

96. *Properties of Hydrogen.* — Hydrogen is colorless, tasteless, and inodorous when quite pure. To obtain it in this condition, it must be prepared from the purest zinc that can be obtained, and passed in succession through solutions of potash and argentic nitrate. It is inflammable and burns with a pale yellowish flame, evolving much heat, but very little light. The result of the combustion is water. It is even less soluble in water than oxygen, and has never been liquefied. Although destitute of poisonous properties, it is incapable of sustaining life.

Hydrogen is the lightest substance known ; Dumas and Boussingault place its density between 0.0691 and 0.0695, referred to that of air as unity. 100 cubic inches weigh about 2.14 grains.

UNIVALENT OR HALOID GROUP OF NON-METALS.

CHLORINE.

97. *Its Preparation, Properties, etc.* — This substance is a member of a very important natural group, containing also iodine, bromine, and fluorine. These bodies (especially chlorine, bromine, and iodine) resemble each other so closely in their chemical relations that the history of one will almost serve, with a few little alterations, for that of the rest.

Chlorine is a very abundant substance. In common salt it exists in combination with sodium. It is most easily prepared by pouring strong muriatic acid upon finely powdered black oxide of manganese contained in a retort or flask, and applying a gentle heat. It is set free as a heavy

yellow gas, which may be collected over warm water, or by displacement.

The reaction is very easily explained. Muriatic acid, as we know (60), is a compound of chlorine and hydrogen: when this is mixed with a metallic monoxide, a double interchange of elements takes place, water and chloride of the metal being produced. Thus $\text{CaO} + 2\text{HCl} = \text{CaCl}_2 + \text{H}_2\text{O}$. But when some of the *dioxides* are substituted, an additional effect ensues — namely, the decomposition of a second portion of acid by the oxygen in excess, the hydrogen of which is withdrawn and the chlorine set free. Thus MnO_2 (manganic dioxide, or black oxide of manganese) $+ 4\text{HCl} = \text{Cl}_2 + \text{MnCl}_2$ (manganic chloride) $+ 2\text{H}_2\text{O}$.

Chlorine was discovered by Scheele in 1774; but its nature was long misunderstood. It is a yellow* gaseous body, of intolerably suffocating properties, producing very violent cough and irritation when inhaled even in a small quantity. It is quite soluble in water, which at 15.5° † absorbs about twice its volume, and acquires the color and odor of the gas. When this *chlorine water*, as it is called, is exposed to light, it is slowly changed, by decomposition of water, into muriatic acid, the oxygen being at the same time liberated. When moist chlorine gas is exposed to a cold of 0° , yellow crystals are formed, which consist of a definite compound of chlorine and water, containing 35.5 parts of the former to 90 of the latter.

Chlorine has a specific gravity of 2.47. Exposed to a pressure of about four atmospheres, it condenses to a yellow limpid liquid.

Chlorine has but little attraction for oxygen, its chemical energies being principally exerted towards hydrogen and the metals. A lighted taper plunged into the gas, con-

* Hence its name, from *χλωρός* (*chloros*), *yellowish-green*.

† Unless otherwise indicated, the temperatures given in this book are *Centigrade*.

tinues to burn with a dull-red light, and emits a large quantity of smoke, the hydrogen of the wax being alone consumed, and the carbon separated. If a piece of paper be wet with oil of turpentine (another compound of hydrogen and carbon), and thrust into a bottle filled with chlorine, the chemical action of the latter upon the hydrogen is so violent as to cause inflammation, accompanied by a copious deposit of soot. Although chlorine can, by indirect means, be made to combine with carbon, yet this never occurs under the circumstances described.

Phosphorus takes fire spontaneously in chlorine, and burns with a pale flame. Copper-leaf, powdered antimony, and arsenic burn in the same way. A mixture of equal measures of chlorine and hydrogen explodes with violence on the passage of an electric spark, or on the application of a lighted taper, muriatic acid gas being formed. Such a mixture may be retained in the dark for any length of time without change; exposed to diffuse daylight, the two gases slowly unite, while the direct rays of the sun cause instant explosion.

The most characteristic property of chlorine is its *bleaching power*. The most stable organic coloring principles are instantly decomposed and destroyed by this remarkable agent. Indigo, for example, which resists the action of strong oil of vitriol, is converted by chlorine into a brownish substance, to which the blue color cannot be restored. The presence of water is essential to these changes, for the gas in a state of perfect dryness is incapable even of affecting litmus. The chlorine seems to decompose the water, setting free the oxygen, which in its *nascent state** attacks and oxidizes the coloring matter.

98. *Its Uses*. — Chlorine is largely used in the arts for

* An element just set free from combination is said to be in the *nascent state*, and often exhibits more energetic properties than under other circumstances.

bleaching linen and cotton goods, rags for the manufacture of paper, etc. For these purposes, it is employed, sometimes in the state of gas, sometimes in that of solution in water, but more frequently in combination with lime, forming the substance called *bleaching-powder*. When required in large quantities, it is often made by pouring slightly diluted sulphuric acid upon a mixture of common salt and manganic dioxide in a large leaden vessel. The reaction is as follows : 2NaCl (salt) + MnO_2 + $2\text{H}_2\text{SO}_4$ (sulphuric acid) = Cl_2 + Na_2SO_4 (sodic sulphate) + MnSO_4 (manganous sulphate) + $2\text{H}_2\text{O}$.

Chlorine is one of the best and most potent substances that can be used for the purpose of *disinfection*, but its employment requires care. Bleaching-powder mixed with water, and exposed to the air in shallow vessels, becomes slowly decomposed by the carbonic acid of the atmosphere, and the chlorine is evolved : if a more rapid disengagement be wished, a little acid of any kind may be added. In the absence of bleaching-powder, the gas may be prepared in either of the ways described above, always taking care to avoid an excess of acid.

99. *Hydric Chloride (Hydrochloric, Chlorhydric, or Muriatic Acid)*. — This gas is prepared by heating in a flask fitted with a cork and bent tube a mixture of common salt and sulphuric acid diluted with a small quantity of water. It must be collected by displacement, or over mercury. It is a colorless gas, which fumes strongly in the air from condensing the atmospheric moisture ; it has an acid, suffocating odor, but is much less offensive than chlorine. Exposed to a pressure of 40 atmospheres, it liquefies.

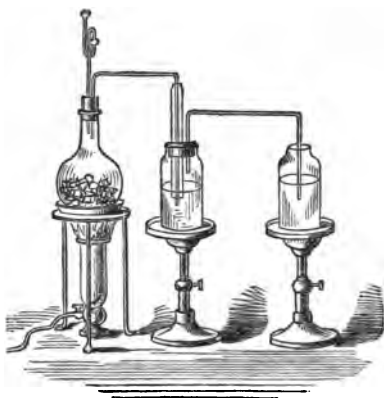
The gas has a density of 1.269. It is exceedingly soluble in water, which takes up at the ordinary temperature about 418 times its bulk. The gas and the solution are powerfully acid.

The action of sulphuric acid on common salt (or any analogous substance) is as follows: $2\text{NaCl} + \text{H}_2\text{SO}_4 = 2\text{HCl} + \text{Na}_2\text{SO}_4$ (sodic sulphate).

The liquid acid is best prepared by the following arrangement:—

A large glass flask, containing a quantity of common salt, is fitted with a cork and bent tube, in the manner represented in Figure 41. This tube passes through and below a second short tube into a wide-necked bottle, containing a little water, into which the open tube dips. A bent tube is adjusted to another hole in the cork of the wash-bottle, so as to carry the purified gas into a quantity of distilled water, by which it is instantly absorbed. The joints are made air-tight by melting a little yellow wax over the corks, or by using rubber-corks.

Fig. 41.



A quantity of sulphuric acid, about equal in weight to the salt, is then slowly introduced by the funnel. The disengaged gas is at first wholly absorbed by the water in the wash-bottle, but when this becomes saturated, it passes into the second vessel and there dissolves. When all the acid has been added, heat may be applied to the flask, until its contents appear nearly dry and the evolution of gas almost ceases, when the process may be stopped. As much heat is given out during the con-

densation of the gas, it is necessary to surround the condensing vessel with cold water.*

The plan employed on the large scale by the manufacturer is the same in principle as that just described. He merely substitutes a large iron cylinder, or apparatus made of lead, for the flask, and vessels of stoneware for those of glass.

Pure solution of hydric chloride is transparent and colorless. When strong, it fumes in the air by evolving a little gas. When saturated with the gas, it has a specific gravity of 1.21, and contains about 42 per cent of real acid. The commercial acid, which is obtained in immense quantity as a secondary product in the manufacture of soda-ash, has usually a yellow color, and is very impure, containing salts, sulphuric acid, iron, and organic matter. It may be rendered sufficiently pure for most purposes by diluting it to

* The simple wash-bottle, shown in the last figure, will be found exceedingly useful in many chemical operations. It serves in the present, and in many similar cases, to retain any liquid or solid matter mechanically carried over with the gas, and it may be always employed when a gas of any kind is to be passed through an alkaline or other solution. The open tube dipping into the liquid prevents the possibility of the formation of a partial vacuum by absorption, and the consequent loss of the liquid in the second vessel by its being driven into the first.

The arrangement by which the acid is introduced also deserves a moment's notice. The tube is bent twice upon itself, and a bulb blown in one portion: the liquid poured into the funnel rises upon the opposite side of the first bend until it reaches the second; it then flows over and runs into the flask. Any quantity can then be got into the latter without the introduction of air, and without the escape of gas from the interior. The funnel acts also as a kind of safety-valve, and in both directions; for if by any chance the delivery-tube should be stopped, and the issue of gas prevented, its increased elastic force soon drives the little column of liquid out of the tube, the gas escapes, and the vessel is saved. On the other hand, any absorption within is quickly compensated by the entrance of air through the liquid in the bulb.

the density of 1.1 (which may be done by mixing the strong acid with its own bulk or rather less of water) and then distilling it in a retort.

100. *Aqua Regia*. — A mixture of nitric and muriatic acids has long been known under the name of *aqua regia* (royal water), from its property of dissolving gold. When these two substances are heated together, they both undergo decomposition, nitric peroxide and chlorine being evolved. This, at least, appears to be the final result of the action: at a certain stage, however, two peculiar substances, consisting of nitrogen, oxygen, and chlorine (*chloronitric acid* gas, NOCl_2 , and *chloronitrous* gas, NOCl), appear to be formed. It is only the chlorine which attacks the metal.*

The presence of muriatic acid, or any other soluble chloride, is easily detected by solution of argentic nitrate. A white curdy precipitate is produced, insoluble in nitric acid, freely soluble in ammonia, and blackening by exposure to light.

101. *Oxides and Oxyacids of Chlorine*. — There are four oxyacids of chlorine, which may be regarded as oxides of hydric chloride; thus: —

Hydric chloride,	HCl
“ hypochlorite (hypochlorous acid),	HClO
“ chlorite (chlorous acid),	HClO_2
“ chlorate (chloric acid),	HClO_3
“ perchlorate (perchloric acid),	HClO_4

The anhydrides corresponding to hydric hypochloride and chlorite are known, viz.: —

Chloric monoxide, or hypochlorous anhydride, Cl_2O .

Chloric trioxide, or chlorous anhydride, Cl_2O_3 .

* This is another illustration of the energetic action of an element in its *nascent state*.

Also an oxide to which there is no corresponding acid, viz. :—

Chloric tetroxide, Cl_2O_4 .

The oxides corresponding to hydric chlorate and perchlorate have not been obtained.

102. *Hypochlorous Anhydride and its Compounds.*—This oxide is best prepared by the action of chlorine gas upon dry mercuric oxide. The reaction is as follows: 2HgO (mercuric oxide) $+ \text{Cl}_2 = \text{Hg}_2\text{Cl}_2\text{O}$ (mercuric oxychloride) $+ \text{Cl}_2\text{O}$.

Hypochlorous anhydride is a pale-yellow gaseous body, containing, in every two measures, two measures of chlorine and one of oxygen, and is therefore analogous in constitution to water. It explodes, although with no great violence, by slight elevation of temperature. Its odor is peculiar, and quite different from that of chlorine. When the flask or bottle in which the gas is received is exposed to artificial cold by the aid of a mixture of ice and salt, the anhydride condenses to a deep-red liquid, slowly soluble in water, and very subject to explosion.

Hydric hypochlorite (hypochlorous acid) is produced by the solution of hypochlorous anhydride in water, or by passing chlorine gas into water holding in solution metallic oxides, hydrates, or salts; the best for the purpose being mercuric oxide, or calcic carbonate (chalk). The reaction when chalk is used is as follows: CaCO_3 (chalk) $+ \text{H}_2\text{O} + \text{Cl}_2 = \text{CO}_2$ (carbonic anhydride) $+ \text{CaCl}_2$ (calcic chloride) $+ 2\text{HClO}$.

The aqueous solution of hydric hypochlorite has a yellowish color, an acid taste, and a characteristic sweetish smell. The strong acid decomposes rapidly even when kept in ice. The dilute acid is more stable, but is decomposed by long boiling into chloric acid, water, chlorine, and oxygen. Muriatic acid decomposes it, with formation of chlorine. $\text{HClO} + \text{HCl} = \text{H}_2\text{O} + \text{Cl}_2$. It is

a very powerful bleaching and oxidizing agent, converting many of the elements — iodine, selenium, and arsenic, for example — into their highest oxides, and at the same time liberating chlorine.

Metallic hypochlorites may be obtained in the pure state by neutralizing hydric hypochlorite with metallic hydrates, as those of sodium, calcium, copper, etc. ; but they are usually prepared by passing chlorine gas into solutions of alkalis or alkaline carbonates, or over dry slaked lime. In this process a metallic chloride is formed at the same time. Thus, $2\text{CaH}_2\text{O}_2$ (slaked lime) $+ \text{Cl}_2 = \text{CaCl}_2\text{O}_2$ (calcic hypochlorite) $+ \text{CaCl}_2$ (calcic chloride) $+ 2\text{H}_2\text{O}$. The salts thus obtained constitute the bleaching and disinfecting salts of commerce. They will be more fully described hereafter.

103. *Chlorous Anhydride and Hydric Chlorite.* — The oxide Cl_2O_3 is a greenish-yellow gas, which is permanent in a freezing mixture of ice and salt, but is liquefied by extreme cold. It dissolves freely in water and in alkaline solutions, forming hydric chlorite and metallic chlorites.

Hydric Chlorite, HClO_2 , may be prepared by condensing chlorous anhydride in water, or by decomposing a metallic chlorite with dilute sulphuric or phosphoric acid. Its concentrated solution is a greenish yellow liquid having strong bleaching and oxidizing properties. It does not decompose carbonates, but acts strongly with caustic alkalies and earths to form chlorites.

104. *Chloric Tetroxide.* — When potassic chlorate is made into a paste with concentrated sulphuric acid, and cooled, and this paste is very cautiously heated by warm water in a small glass retort, a deep-yellow gas is evolved, which is chloric tetroxide. It can be collected only by displacement, since mercury decomposes and water absorbs it. The reaction is as follows: 6KClO_3 (potassic chlorate) $+ 3\text{H}_2\text{SO}_4 = 2\text{Cl}_2\text{O}_4$ (chloric tetroxide) $+ 2\text{HClO}_4$

(hydric perchlorate) + $3K_2SO_4$ (potassic sulphate) + $2H_2O$.

Chloric tetroxide has a powerful odor, quite different from that of the preceding compounds, and of chlorine itself. It is exceedingly explosive, being resolved with violence into its elements by a temperature short of the boiling-point of water. Its preparation is, therefore, always attended with danger, and should be performed only on a small scale. It is composed by measure of one volume of chlorine and two volumes of oxygen, condensed into two volumes. It may be liquefied by cold. The solution of the gas in water bleaches.

When a mixture of potassic chlorate and sugar is touched with a drop of oil of vitriol, it is instantly set on fire, the chloric tetroxide disengaged being decomposed by the combustible substance with such violence as to cause inflammation. If crystals of potassic chlorate be thrown into a glass of water, a few small fragments of phosphorus added, and then oil of vitriol poured down a narrow funnel reaching to the bottom of the glass, the phosphorus will burn beneath the surface of the water, by the assistance of the oxygen disengaged from the chloric tetroxide. The liquid at the same time becomes yellow, and acquires the odor of that gas.

105. *Hydric Chlorate (Chloric Acid)*. — This is the most important compound of the series. When chlorine is passed to saturation into a moderately strong hot solution of potassic oxide or carbonate, and the liquid concentrated by evaporation, it yields, on cooling, flat tabular crystals of a colorless salt, potassic chlorate. The mother-liquor contains potassic chloride. $3K_2O$ (potassic oxide), + $Cl_6 = 5KCl$ (potassic chloride) + $KClO_3$ (potassic chlorate).

From potassic chlorate, hydric chlorate may be obtained by boiling the salt with a solution of hydrofluosilicic acid,

which forms an almost insoluble potassic salt, decanting the clear liquid, and digesting it with a little silica, which removes the excess of the hydrofluosilicic acid. Filtration through paper must be avoided.

By cautious evaporation, the acid may be so far concentrated as to assume a sirupy consistence; it is then very easily decomposed. It sometimes sets fire to paper, or other dry organic matter, in consequence of the facility with which it is deoxidized by combustible bodies.

106. *Hydric Perchlorate (Perchloric Acid)*.—When powdered potassic chlorate is thrown by small portions at a time into hot nitric acid, chlorine and oxygen are emitted in a state of *mixture*. The result of the reaction is a mixture of potassic nitrate and perchlorate, which may be readily separated by their difference of solubility.

Hydric perchlorate is obtained by distilling potassic perchlorate with sulphuric acid. It is a colorless liquid, of 1.782 sp. gr. at 15.5°, not solidifying at —35°; it soon becomes colored, even if kept in the dark, and after a few weeks decomposes with explosion. Its vapor is transparent and colorless: in contact with moist air, it produces dense white fumes. When brought in contact with carbon, ether, or other organic substances, hydric perchlorate explodes with the greatest violence.

107. *Compound of Chlorine and Nitrogen*.—When sal-ammoniac is dissolved in water, and a jar of chlorine inverted in the solution, the gas is absorbed, and a deep-yellow oily liquid is observed to collect upon the surface of the solution, ultimately sinking in globules to the bottom. This is *nitric chloride* (chloride of nitrogen), the most dangerously explosive substance known. The reaction is, perhaps, as follows: NH_4Cl (ammonic chloride, or sal-ammoniac) + $6\text{Cl} = 4\text{HCl} + \text{NCl}_3$ (nitric chloride).

Nitric chloride is very volatile, and its vapor is exceed-

ingly irritating to the eyes. It has a specific gravity of 1.653. It may be distilled at 71° , although the experiment is attended with great danger. Between 93° and 105° it explodes with the most fearful violence. Contact with almost any combustible matter, as oil or fat of any kind, causes the explosion at common temperatures: a vessel of porcelain, glass, or even of cast-iron, is broken to pieces, and a leaden cup receives a deep indentation. This body has usually been supposed to contain nitrogen and chlorine in the proportion of 14 parts of the former to 106.5 parts of the latter, but recent experiments make it probable that it contains hydrogen. Instead of NCl_3 , it may in reality be NHCl_2 , or NH_2Cl .

BROMINE.

108. *Its History, Properties, etc.* — Bromine was discovered by Balard in 1826. It is found in sea-water, and is a frequent constituent of saline springs, chiefly as magnesian bromide. A celebrated spring of the kind exists near Kreuznach in Prussia.

Bromine is at common temperatures a thin liquid of an exceedingly intense red color, and very volatile; it freezes at about -22° and boils at 63° . The density of the liquid is 2.976, and that of the vapor 5.54 compared with air, and 80 compared with hydrogen. The odor of bromine is very suffocating and offensive, much resembling that of iodine, but more disagreeable. Hence its name, from $\beta\rho\omega\mu\omicron\varsigma$ (*bromos*), a noisome smell. It is slightly soluble in water, more freely in alcohol, and most abundantly in ether. The aqueous solution bleaches.

109. *Hydric Bromide (Hydrobromic Acid).* — This substance bears the closest resemblance to hydric chloride: it has the same constitution by volume, very nearly the same properties, and may be prepared by means exactly

similar. Its solution has the power of dissolving a large quantity of bromine, thereby acquiring a red tint. It contains by weight 80 parts bromine and 1 part hydrogen, and its symbol is HBr .

110. *Hydric Bromate (Bromic Acid)*. — Caustic alkalies in presence of bromine undergo the same change as with chlorine (105), a metallic bromide and bromate being produced : these may often be separated by the inferior solubility of the latter. Hydric bromate, HBrO_3 , obtained from baric bromate, closely resembles hydric chlorate : it is easily decomposed. The bromates, when heated, lose oxygen and become bromides.

IODINE.

111. *Its History, Preparation, Properties, etc.* — This element was first noticed in 1812 by M. Courtois, of Paris. Minute traces are found in combination with sodium or potassium in sea-water, and occasionally a much larger proportion in that of certain mineral springs. It seems to be in some way beneficial to many marine plants, as these latter have the power of abstracting it from the surrounding water, and accumulating it in their tissues. It is from this source that all the iodine of commerce is derived. It has lately been found in minute quantity in some aluminous slates of Sweden, and in several varieties of coal and turf.

Kelp, or the half-vitrified ashes of sea-weeds, prepared by the inhabitants of the Western Islands and the northern shores of Scotland and Ireland, is treated with water, and the solution filtered. The liquid is then concentrated by evaporation until it is reduced to a very small volume, the sodic chloride, sodic carbonate, potassic chloride, and other salts being removed as they successively crystallize. The dark-brown mother-liquor left contains very nearly the

whole of the iodine, in the form of iodides : this is mixed with sulphuric acid and manganic dioxide, and gently heated in a leaden retort, when the iodine distils over and condenses in the receiver.

Iodine crystallizes in plates or scales of a bluish-black color and imperfect metallic lustre, resembling that of plumbago : the crystals are sometimes very large and brilliant. Its density is 4.948. It melts at 107° and boils at 175° , the vapor having an exceedingly beautiful violet color ; whence its name, from *ἰώδης* (*iodēs*), violet-colored. It is slowly volatile, however, at common temperatures, and exhales an odor much resembling that of chlorine. The density of the vapor is 8.716 compared with air, 127 compared with hydrogen. Iodine requires for solution about 7,000 parts of water, which nevertheless acquires a brown color ; in alcohol it is much more freely soluble. Solutions of hydric iodide and the iodides of the alkaline metals also dissolve a large quantity.

Iodine stains the skin, but not permanently ; it has a very energetic action upon the animal system, and is much used in medicine.

One of the most characteristic properties of iodine is the production of a splendid blue color by contact with starch. The iodine for this purpose must be free or uncombined. If, however, it is in the form of soluble iodide, a little chlorine-water will serve to set it free, so that it can act upon the starch.

112. *Hydric Iodide (Hydriodic Acid)*. — The simplest process for preparing this gas is to introduce into a glass tube, sealed at one extremity, a little iodine, then a small quantity of roughly powdered glass moistened with water, upon this a few fragments of phosphorus, and lastly more glass : this order of iodine, glass, phosphorus, glass, is repeated until the tube is half or two-thirds filled. A cork and narrow bent tube are then fitted, and gentle heat ap-

plied. The gas is best collected by displacement of air. The experiment depends on the formation of a phosphoric iodide and its subsequent decomposition by water, whereby hydric phosphite and hydric iodide are produced. $P_2 + I_6 + 6H_2O = 6HI$ (hydric iodide) $+ 2H_3PO_3$ (hydric phosphite). The glass merely serves to moderate the violence of the action of the iodine upon the phosphorus.

Hydric iodide gas greatly resembles the corresponding chlorine compound. It is colorless, and highly acid; it fumes in the air, and is very soluble in water. Its density is about 4.4 compared with air, 64 compared with hydrogen. By weight, it is composed of 127 parts iodine and 1 part hydrogen; and by measure, of equal volumes of iodine vapor and hydrogen united without condensation.

113. *Compounds of Iodine and Oxygen.* — The most important of these are the *iodic* and *periodic anhydrides*, I_2O_5 and I_2O_7 .

Both these unite with water and metallic oxides, forming salts called *iodates* and *periodates*.

Hydric iodate (iodic acid), HIO_3 , is a very soluble substance; it crystallizes in colorless, six-sided tables. At 107° it is resolved into water and iodic anhydride, which forms tabular rhombic crystals, and, when heated to the temperature of boiling olive oil, is completely resolved into iodine and oxygen. The iodates much resemble the chlorates: that of potassium is decomposed by heat into potassic iodide and oxygen gas.

Hydric periodate (periodic acid), HIO_4 , crystallizes from its aqueous solution in deliquescent oblique rhombic prisms, which melt at 130° , and are resolved at 170° into water and a white mass of periodic anhydride, which at 180° or 190° gives off oxygen with great rapidity, and leaves iodic anhydride. The metallic periodates are resolved by heat into oxygen and metallic iodides.

114. *Compounds of Iodine and Nitrogen.* — When finely

powdered iodine is put into caustic ammonia, it is in part dissolved, giving a deep-brown solution, and the residue is converted into a black powder, called *nitric iodide*, NI_3 . The brown liquid consists of hydric iodate, holding iodine in solution, and is easily separated from the solid product by a filter. The latter, while still wet, is distributed in small quantities upon separate pieces of bibulous paper, and left to dry in the air.

Nitric iodide is a black insoluble powder, which, when dry, explodes at the slightest touch, — even that of a feather, — and sometimes without any obvious cause. The explosion is, however, not nearly so violent as that of nitric chloride, and is attended with the production of violet fumes of iodine. According to Dr. Gladstone, this substance contains hydrogen, and may be viewed as ammonia in which two atoms of hydrogen are replaced by iodine, NHI_2 . According to the researches of Bunsen, it must be viewed as a combination of nitric tri-iodide with ammonia, $\text{NI}_3\text{H}_3\text{N}$. It appears, however, that the substance called nitric iodide varies in composition. Gladstone, by changing the mode of preparation, obtained several compounds of nitric tri-iodide with ammonia.

FLUORINE.

115. *Its Properties.* — This element has never been isolated — at least, in a state fit for examination. Its properties are consequently in great measure unknown; but from the observations made, it is presumed to be gaseous, and to possess color, like chlorine. The compounds containing fluorine can be easily decomposed, and the element transferred from one body to another; but its intense chemical action upon the metals and upon silicon, a component of glass, have hitherto baffled all attempts to obtain it pure in the separate state. As calcic fluoride, it exists in

small quantities in many animal substances, such as bones. Several chemists have endeavored to obtain it by decomposing argentic fluoride by means of chlorine in vessels of fluor-spar, but even these experiments have not led to a decisive result.

116. *Hydric Fluoride (Hydrofluoric Acid)*. — When powdered calcic fluoride (fluor-spar) is heated with concentrated sulphuric acid in a retort of platinum or lead connected with a carefully cooled receiver of the same metal, a very volatile colorless liquid is obtained, which emits copious white and highly suffocating fumes in the air. This was formerly believed to be pure hydric fluoride, HF. Louyet, however, states that it still contains water, and that hydric fluoride, like hydric chloride, is a gas, which may be prepared, according to Frémy, by distilling hydrogen and potassic fluoride in a platinum vessel. The acid is gaseous at ordinary temperatures. In a freezing mixture it exists as a liquid, which acts violently on water and evolves white fumes.

When hydric fluoride is put into water, it unites with the latter with great violence; the dilute solution attacks glass very quickly. The concentrated solution, if dropped upon the skin, occasions deep and malignant ulcers, so that great care is requisite in its management.

This liquid is employed for etching on glass, for which purpose it may be prepared in vessels of lead, that metal being but slowly attacked under these circumstances. The vapor is also very advantageously applied to the same object in the following manner: The glass to be engraved is coated with wax, and the design traced with a pointed instrument. A shallow basin made by beating up a piece of sheet-lead is then prepared, a little powdered fluor-spar placed in it, and enough sulphuric acid added to form a thin paste. The glass is placed upon the basin, with the waxed side downwards, and gentle heat applied

beneath, which speedily disengages the vapor of hydrofluoric acid. In a very few minutes, the operation is complete; the glass is then removed and cleaned by a little warm oil of turpentine. When the experiment is successful, the lines are very clean and smooth.

No compound of fluorine and oxygen has yet been discovered.

117. *The Chlorine Group.* — The four elements just described form a well-marked group. They are especially remarkable for their gradation of properties. Thus chlorine is a gas, bromine a liquid, and iodine a solid, at the ordinary temperature. Chlorine may be easily condensed into a liquid, and the specific gravity of liquid chlorine is 1.33, of bromine 2.97, and of iodine 4.95. Liquid chlorine is transparent, bromine slightly so, and iodine opaque. The atomic weight and density of bromine are nearly the mean of those of chlorine and iodine, $\frac{35.5 + 127}{2} = 81.25$; and in its general chemical deportment bromine stands half-way between the other two elements.

A similar gradation is noticeable also in the properties of many of their compounds. Thus, the specific gravity of hydric chloride is 18.2, that of hydric bromide is 40.5, and that of hydric iodide 64; the first liquefies at about -80° , the second at -60° , and the third at -40° ; and so on.

That which distinguishes these substances from the rest of the elements is their power of forming compounds with hydrogen which contain equal volumes of the constituent gases united without condensation. They all have a weak affinity for oxygen.

OXYGEN OR BIVALENT GROUP OF NON-METALS.

OXYGEN.

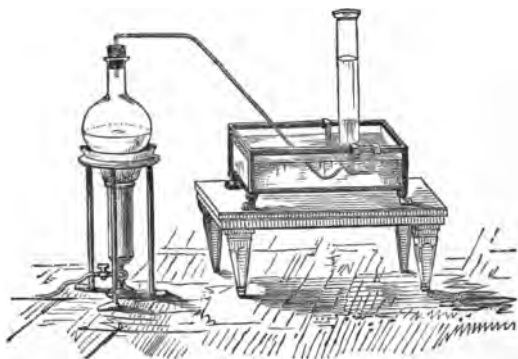
118. *Its History, Preparation, etc.* — Oxygen was discovered in the year 1774, by Scheele, in Sweden, and Priestley, in England, independently of each other, and described under the terms *empyreal air* and *dephlogisticated air*. The name *oxygen* or *acid-maker* (from $\acute{o}\xi\gamma\acute{\epsilon}\nu$, *acid*, and $\gamma\epsilon\nu$, a root signifying *production*) was given to it by Lavoisier some time afterwards. Oxygen exists in a free and uncombined state in the atmosphere, mingled with nitrogen. As there is no very good method of separating the two gases, oxygen is always obtained for purposes of experiment by decomposing certain of its compounds, which are very numerous.

The red mercuric oxide, or *red precipitate* of the old writers, may be employed with this view. In this substance the attraction which holds together the mercury and the oxygen is so feeble, that simple exposure to heat suffices to bring about decomposition. The red precipitate is placed in a small flask of hard glass, furnished with a glass delivery-tube, and is then heated by a lamp (Figure 42). The gas is at once given off, and may be collected by the aid of the pneumatic trough. The reaction is as follows: HgO (mercuric oxide) $= \text{Hg} + \text{O}$.

A better and more economical method is to heat in a retort, or flask furnished with a bent tube, the salt called potassic chlorate. A common Florence flask serves perfectly well, the heat of a spirit-lamp being sufficient. The salt melts and decomposes with ebullition, yielding a very large quantity of oxygen gas, which may be collected in the way above described. The first portion of the gas

often contains a little chlorine. The white saline residue in the flask is potassic chloride. This plan is always adopted

Fig. 42.



when very pure gas is required. The reaction is as follows: $\text{KClO}_3 = \text{KCl} + \text{O}_3$.

If a little of the black oxide of manganese be finely powdered and mixed with potassic chlorate, and this mixture heated in a flask or retort by a lamp, oxygen will be disengaged with the utmost facility, and at a far lower temperature than when the chlorate alone is used.* All the oxygen comes from the chlorate, the manganese remaining

* As explosions sometimes occur in the manufacture of oxygen, care should be taken that the chemicals are pure; and it would be well to test each purchase by putting some of the potassic chlorate in an iron spoon and heating it over a spirit lamp until it is melted; then stir into it with an iron wire some of the black oxide of manganese; and if these materials are not good, an explosion will take place, and a whitish mass with red spots in it will be left in the spoon. If, however, the chemicals are pure, there will be no explosion, and the melted mixture will soon dry up, leaving a dark gray residuum. If the bubbles come over too violently, remove the lamp for a few minutes until they come more moderately.

As a glass flask is liable to break, a copper flask may be found cheaper in the long run, especially if one has to make oxygen often.

quite unaltered. The materials should be well dried before use.

This experiment affords an instance of an effect by no means rare, in which a body seems to act by *mere presence*, without taking any obvious part in the change brought about. This action is often called *catalysis*.

A new method of obtaining oxygen cheaply and abundantly has recently been discovered by Tessié du Mothay and Maréchal, in France. It is virtually a method of drawing a supply of the gas from the atmosphere through the agency of manganese. The discovery originated in the ascertaining of two facts: (1) that if a current of steam passes over sodic manganate (manganate of soda), it will abstract and carry away a considerable portion of the oxygen, which can afterward be separated and secured by the simple condensation of the steam; and (2) that if a current of air be passed over the partially deoxidized compound, the compound will recover from the air the portion it had lost. When this is done a new current of steam may be employed to take off a second portion, to be followed by a new current of air, to restore it again; and so on indefinitely.

It will be observed that, in this process, the real source of the oxygen obtained is the atmosphere; the manganese being merely the means by which it is collected and isolated.

119. *Its Properties*.—Oxygen, when free or uncombined, is known only in the gaseous state, all attempts to reduce it to the liquid or solid condition by cold and pressure having completely failed. It is, bulk for bulk, a little heavier than atmospheric air, its specific gravity being 1.10563, referred to that of air as unity, and 16 referred to that of hydrogen as unity. When pure, it is colorless, tasteless, and inodorous. It is the sustaining principle of animal life, and of all the ordinary phenomena of combustion.

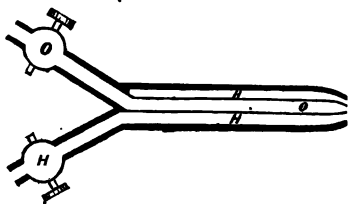
Bodies which burn in the air burn with greatly increased splendor in oxygen gas. If a taper be blown out, and then introduced into the gas while the wick remains red-hot, it is instantly rekindled: a slip of wood or a match is re-lighted in the same manner. This effect serves as a test of oxygen, there being but one other gas which possesses the same property; and this is easily distinguished by other means.

When a bit of charcoal is affixed to a wire, and plunged with a single point red-hot into a jar of oxygen, it burns with great brilliancy, throwing off beautiful scintillations, until, if the oxygen be in excess, it is completely consumed. An iron wire, or, still better, a steel watch-spring, armed at its extremity with a bit of lighted wood, and introduced into oxygen, takes fire and burns as readily as a match does in the air. Kindled sulphur burns with great beauty in oxygen; and phosphorus blazes with dazzling splendor.

If soap-bubbles are blown with a mixture of two measures of hydrogen to one of oxygen, they will explode violently when touched with a lighted taper; showing the intense energy with which hydrogen and oxygen combine at a high temperature. The compound formed is *water*.

120. *The Oxy-hydrogen Blowpipe.* — The energy with

Fig. 43.

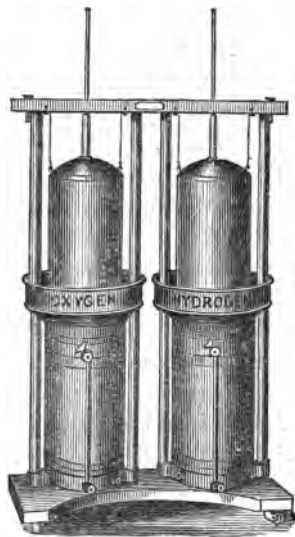


which hydrogen and oxygen combine develops intense heat. This may be shown by means of the *oxy-hydrogen blowpipe*, represented in Figure 43. The hydrogen is forced through the tube *H*, and the

oxygen through the tube *O*; and it will be seen that the

two can mix only at the mouth of the jet where they are burned, so that there is no danger of an explosion. The gases may be kept in a *gasometer* (Figure 44), or, more conveniently, in gas-bags of india-rubber.

Fig. 44.



Hold a copper or iron wire in the flame of this blowpipe, and it burns as readily as a pine shaving held in the flame of a lamp. A steel watch-spring burns with brilliant scintillations. If a bit of zinc be placed on a piece of charcoal hollowed out for the purpose, and the flame of the blowpipe be directed upon it, the metal quickly melts and burns. Antimony, bismuth, and many other metals will burn in the same way, each with a characteristic light. Cast-iron burns with a shower of bright sparks. Platinum, which is one of the most infusible of substances, is readily melted, and even converted into vapor.

A small cylinder of lime placed in the blowpipe flame becomes white-hot, and glows with most intense brilliancy, forming what is known as the *lime light*, *calcium light*, or *Drummond light*. When the rays of this light have been gathered and reflected by a mirror, it has been seen at a distance of one hundred miles in full daylight.

The above experiments illustrate several properties of oxygen : (1) the *passive state in which it exists under ordinary circumstances*, it being necessary to *heat* it in order to make it combine rapidly with most substances ; (2) the *in-*

tense energy with which it enters into combination when once aroused; and (3) the wide range of its affinities. It combines with every known element, except fluorine.

WATER.

121. *Its Properties.* — The most important non-metallic oxide is *water*.

At ordinary temperatures water is a clear, colorless, transparent liquid, without taste or smell. It freezes at 32° F., and under the ordinary pressure of the atmosphere it boils at about 212° F.

It is the most universal *solvent* known. There are but few substances which are not dissolved by it. Even those which we call insoluble generally differ from the rest only in degree. Spring-water dissolves lime-rocks, and almost all other mineral substances. The beautiful crystals found in the rocks are almost invariably deposited from a solution of the mineral in water, though in many cases it may have taken thousands of years to form them.

When water is heated in a strong vessel to a temperature above that of the ordinary boiling-point, its solvent powers are still further increased. Dr. Turner enclosed in the upper part of a high-pressure steam-boiler, worked at 149° C. (300°F.), pieces of plate and crown-glass. At the expiration of four months the glass was found completely corroded by the action of the water; what remained was a white mass of silica, destitute of alkali, while stalactites of silicious matter, above an inch in length, depended from the little wire cage which enclosed the glass. This experiment tends to illustrate the changes which may be produced by the action of water at a high temperature in the interior of the earth upon rocks, as in the Geyser springs of Iceland, which deposit silicious sinter.

Water dissolves almost all *gases* as well as solids. It is

on the gases dissolved in the water that all aquatic plants and animals live.

122. *Various Kinds of Natural Waters.*—Owing to its solvent powers, water is never found in nature in a state of purity. *Rain water*, collected after long-continued wet weather, comes nearest to it; but even this always contains small quantities of atmospheric air, and the gases floating in the air.

Spring water always contains more or less of saline matter, which it has dissolved from the soil. The salts most frequently found in it are common salt, calcic carbonate and sulphate (carbonate and sulphate of lime), and magnesian carbonate and sulphate (carbonate and sulphate of magnesia). Most spring water contains carbonic acid, to which it owes its sprightly taste.

Mineral waters are waters which contain an unusually large proportion of any of the salts just named, or of other and rarer substances. In many cases they have medicinal qualities, which vary with the salts held in solution. They sometimes contain salts of iron, and are then called *chalybeate* springs. In other instances, carbonic acid is so abundant as to give them an *effervescent* character. Less frequently *sulphur* is the chief ingredient, giving the water a nauseous taste and smell.

Water is familiarly called *hard* or *soft*, according to its action on soap. Hard waters contain salts of calcium or magnesium, which cause the soap to *curdle*, that is, to become insoluble. Soft waters do not contain these salts, and dissolve the soap without difficulty. Many hard waters become soft by boiling, the salts held in solution being ~~deposited~~, as a *fur* or crust, on the inside of the boiler.

Sea water contains a large amount of common salt and of magnesian chloride (chloride of magnesium), to which it owes its saline, bitter taste. Smaller quantities of many

other salts are found in it. All this matter has been washed out of the soil by the rivers which flow into the sea. It remains in the sea, since the water which evaporates from the surface is almost perfectly pure ; but the surplus is continually taken up by marine plants and animals, so that the sea becomes no salter.

123. *Water in Plants and Animals.* — Water constitutes the greater part of all plants and animals. The human body is four fifths water. In many of the lower animals the proportion is much greater. From a sun-fish weighing 30 pounds, only 240 grains of solid matter were obtained ; so that water makes up about .999 of the weight of such animals. The vegetable substances which we use for food contain almost as large a percentage of water. In potatoes, the fraction is .75 ; in apples, .80 ; in turnips, .90 ; in watermelons, .94 ; and in cucumbers, .97.

124. *Water of Crystallization.* — Many salts, in crystallizing from their solutions, unite with a definite quantity of water, which is then called *water of crystallization*. If the salt be heated, the water is driven off, and the crystals fall to pieces ; but the chemical properties of the substance are not altered. Many salts part with this water by mere exposure to the air, and *effloresce* ; that is, crumble into white powder. Sodid carbonate (carbonate of soda) is an efflorescent salt. Other salts, on the contrary, like potassic carbonate (carbonate of potash), absorb water from the air, and become moist, or even dissolve ; in which case they are said to *deliquesce*.

125. *Uses of Water.* — “On the uses of water it is almost needless to enlarge, for they are universally felt and appreciated. In each of its three physical conditions, the blessings which it confers on man are inestimable. As ice, it furnishes in northern lands, for months together, a solid bridge of communication between distant places ; in the liquid condition, it is absolutely necessary to the existence

of vegetable and animal life ; in this shape, too, it furnishes to man a continual source of power in the flow of streams and rivers ; it supplies one of the most convenient channels of communication between places widely separated ; and further, it is the storehouse of countless myriads of creatures fitted for use as food : in the state of vapor, as applied in the steam-engine, it has furnished a power which has, in late years, done more than any other physical agent to advance civilization, to economize time, and to ameliorate the social condition of men. In each and all of these points, if rightly considered, we must perceive the entire adaptation of this compound to the ends which it was designed by the Creator to serve.

“Glancing at the physical condition of our planet, we cannot fail to be impressed with the important effects produced by the movements of water at periods anterior to the existence of man, as well as in more recent times. To such causes must we refer the formation of sedimentary rocks, and their arrangement in successive strata upon the surface of the earth ; even now, observation shows that denudation is proceeding at some points, elevation and filling-up at others ; whilst the accumulation of drift, and a variety of other extensive geological changes, must be traced to the same ever-acting and widely operating agency.

“It may further be observed that there is no form of matter which contributes so largely as water to the beauty and variety of the globe which we inhabit. In its solid state, we are familiar with it, in the form of blocks of ice, of sleet and hail, of hoar-frost fringing every shrub and blade of grass, or of snow protecting the tender plant, as with a fleecy mantle, from the piercing frosts of winter. The rare but splendid spectacles of mock suns, or *parhelia*, are due to the refractive power of floating spiculæ of ice upon the sun’s rays. In its liquid condition, as rain or

dew, it bathes the soil ; and the personal experience of all will testify to the charm which the waterfall, the rivulet, the stream, or the lake adds to the beauty of the landscape ; whilst few can behold unmoved the unbounded expanse of ocean, which, whether motionless, or heaving with the gently undulating tide, or when lashed into fury by the storm which sweeps over its surface, seems to remind man of his own insignificance, and of the power of Him who alone can lift up or quell its roaring waves. In vapor, how much variety is added to the view by the mist or the cloud, which, by their ever-changing shadows, diversify, at every movement, the landscape over which they are flitting ; whilst the gorgeous hues of the clouds around the setting sun, and the glowing tints of the rainbow, are due to the refractive action of water and watery vapor upon the solar rays." *

126. *Hydric Dioxide*.—This compound, sometimes called *oxygenated water*, is exceedingly interesting, but very difficult to prepare. It is formed by dissolving baric dioxide in dilute muriatic acid carefully cooled by ice, and then precipitating the barium by sulphuric acid ; the excess of oxygen of the dioxide, instead of being disengaged as gas, unites with a portion of the water, and converts it into hydric dioxide. This treatment is repeated with the same solution and fresh portions of the baric dioxide, until a considerable quantity of the latter has been consumed, and a corresponding amount of hydric dioxide formed. The liquid yet contains muriatic acid, to get rid of which it is treated in succession with argentic sulphate and baryta-water. The whole process requires the utmost care and attention. The baric dioxide itself is prepared by exposing pure baryta, contained in a red-hot porcelain tube, to a stream of oxygen. The solution of hydric dioxide may be concentrated under the air-pump receiver until it acquires

* Miller's Elements of Chemistry, Part II. pp. 35, 36.

the specific gravity of 1.45. In this state it presents the aspect of a colorless, transparent, inodorous liquid, possessing remarkable bleaching powers. It is very prone to decomposition; the least rise of temperature causes effervescence, due to the escape of oxygen gas; near 100° it is decomposed with explosive violence. Hydric dioxide contains exactly twice as much oxygen as water, or 16 parts to 1 part of hydrogen. Its formula is H_2O_2 .

A *hydric trioxide* is said to exist, although it has never been obtained in the pure state. It is likewise a powerful oxidizing agent, and altogether similar in its properties to the dioxide. According to the researches of Dr. Baumert, minute quantities of this substance are formed in the decomposition of water by electricity.

OZONE.

127. *Its Preparation, etc.*—It has long been known that dry oxygen, or atmospheric air, when exposed to the action of a series of electric sparks, emits a peculiar and somewhat metallic odor. The same odor may be imparted to moist oxygen by allowing phosphorus to remain for some time in it, and by several other processes. A more accurate examination of this odorous air has shown that, in addition to the smell, it possesses several properties not exhibited by oxygen in its ordinary state. One of its most characteristic effects is the liberation of iodine from potassic iodide. This odorous principle has been the subject of many researches, in particular by Schönbein, of Basle, who proposed for it the name of *ozone* from $\delta\zeta\omega$ (*ozo*), *to emit an odor*.

An easy method of obtaining ozone is to transmit a current of oxygen through a tube into which two platinum wires are sealed, with the points at a little distance apart. On connecting one of the wires with the prime con-

ductor of an electrical machine in good action, and the other with the ground, the characteristic odor of ozone is immediately developed in the issuing gas; but, notwithstanding the powerful odor, only a small portion of the oxygen undergoes this change. Andrews and Tait have shown that, to obtain the maximum of ozone, it is necessary to transmit the discharge silently, between very fine points; if sparks are allowed to pass, a considerable portion of the ozone is reconverted into ordinary oxygen as fast as it is formed. Siemens prepares ozone by induction. He forms a sort of Leyden jar, by coating the interior of a long tube with tin-foil, and passes over this tube a second wider tube coated with tin-foil on its outer surface. Between the two tubes a current of pure dry oxygen is passed, which becomes electrified by induction, on connecting the inner and outer coating with the terminal wires of an induction-coil. By this means it is said that from 10 to 15 per cent of the oxygen may be converted into ozone.

Ozone may also be obtained in several ways, without the aid of electricity; thus it is formed in small quantity when a stick of phosphorus is suspended in a bottle filled with moist air; by the slow oxidation of ether, oil of turpentine, and other essential oils; in the electrolytic decomposition of water; and by the action of strong sulphuric acid on potassic permanganate. There has been considerable discussion about the nature and composition of ozone; but the most trustworthy experiments seem to show that, in whatever way produced, it is merely *a modified form of oxygen*.

128. *Its Properties.* — Ozone is insoluble in water and in solutions of acids or alkalies, but is absorbed by a solution of potassic iodide. Air charged with it exerts an irritating action on the lungs. Ozone is decomposed by heat, gradually at 100°, instantly at 290°. It is an extremely powerful oxidizing agent; possesses strong bleaching and

disinfecting powers ; corrodes cork, caoutchouc, and other organic substances ; and rapidly oxidizes iron, copper, and even silver when moist, as well as dry mercury and iodine. It is remarkable that the absorption of ozone by these and other agents is not attended with any contraction of volume. The explanation of this fact appears to be, that oxygen when ozonized diminishes in volume (in the proportion of 3 to 2, according to Soret), and that, when the ozone is decomposed by a metal or other substance, one portion of it enters into combination, while the remainder, which is set free as ordinary oxygen, occupies the same bulk as the ozone itself.

The most delicate test for the presence of ozone in any gas is afforded by a strip of paper moistened with a mixture of starch and solution of potassic iodide. On exposing such paper to the action of ozone, the potassic iodide is decomposed, its potassium combining with oxygen while the iodine is liberated, and forms a deep blue compound with the starch. Now, when paper thus prepared is exposed to the open air for five or ten minutes, it often acquires a blue tint, the intensity of which varies on different days. Hence it has been plausibly supposed that ozone is present in the air in variable quantity. But iodine may be liberated from potassic iodide by many other agents, especially by certain oxides of nitrogen, which are very likely to be present in the air in minute quantities : hence the existence of ozone in the air cannot be proved by this reaction alone.

SULPHUR.

129. *Its Nature and Properties.* — Sulphur is an element of great importance and interest. It is found often in a free state in connection with deposits of gypsum and rock salt. Its occurrence in volcanic districts is probably accidental.

Sicily furnishes a large part of the sulphur used in Europe. It is also found abundantly in combination with iron and other metals, and as calcic and magnesian sulphates.

Pure sulphur is a pale-yellow brittle solid, of well-known appearance. It melts when heated, and distils over unaltered, if air be excluded. The crystals of sulphur exhibit two distinct and incompatible forms: first, an octohedron with rhombic base (see Figure 22, 4), which is the figure of native sulphur, and that assumed when sulphur separates from solution at common temperatures, as when a solution of sulphur in carbonic disulphide is exposed to

Fig. 45.



slow evaporation in the air; and, second, a lengthened prism having no relation to the preceding. The latter form appears when sulphur is melted, and, after partial cooling, the crust on the surface is broken and the fluid portion poured out. Figure 45 shows the result of such an experiment.

The specific gravity of sulphur varies according to the form in which it is crystallized. The octohedral variety has the specific gravity 2.045; the prismatic variety, 1.982.

Sulphur melts at 111° (at 114.5° , according to Brodie). At this temperature it is of the color of amber, and thin and fluid as water; when further heated, it begins to thicken, and to acquire a deeper color; and between 221° and 249° it is so tenacious that the vessel in which it is contained may be inverted for a moment without spilling it. If in this state it be poured into water, it retains for many hours a remarkably soft and flexible condition, which should be looked upon as the *amorphous* state of sulphur. After a while it again becomes brittle and crystalline. From the temperature last mentioned to the boiling-point — about 400° — sulphur again becomes thin and liquid. In the

preparation of commercial *flowers of sulphur*, the vapor is conducted into a large cold chamber, where it condenses in minute crystals. The specific gravity of sulphur vapor is 2.22, referred to that of air as unity, or 32 compared with that of hydrogen (Deville).

Sulphur is insoluble in water and alcohol ; oil of turpentine and the fat oils dissolve it, but the best substance for the purpose is carbonic disulphide. In its chemical relations sulphur bears great resemblance to oxygen : to very many oxides there are corresponding sulphides, and the sulphides often unite among themselves, forming crystallizable compounds analogous to oxygen salts.

Sulphur is remarkable for the great number of modifications which it is capable of assuming. Of these, however, there are two principal well-characterized varieties — one soluble, and the other insoluble in carbonic disulphide — and many minor modifications. The soluble variety is distinguished by Berthelot by the name of *electro-negative sulphur*, because it is the form which appears at the positive pole of the battery during the decomposition of an aqueous solution of hydric sulphide, and is separated from the compounds of sulphur with the electro-positive metals. The insoluble variety is distinguished as *electro-positive sulphur*, because it is the form which appears at the negative pole during the electric decomposition of sulphurous anhydride, and separates from compounds of sulphur with the electro-negative elements, chlorine, bromine, oxygen, etc.

130. *Compounds of Sulphur and Oxygen.* — There are two oxides of sulphur whose names and composition are as follows : —

Sulphuric dioxide or sulphurous anhydride, SO_2 .

“ trioxide or sulphuric “ SO_3 .

There are also several acids of sulphur, with their corresponding metallic salts, to which there are no corresponding anhydrides : —

(1.) *Hydric hyposulphite* (hyposulphurous acid), having the composition $\text{H}_2\text{S}_2\text{O}_3$.

(2.) A series of acids called *polythionic acids*, in which the same quantities of oxygen and hydrogen are united with quantities of sulphur in the proportion of the numbers 2, 3, 4, 5; viz. :—

Dithionic acid, $\text{H}_2\text{S}_2\text{O}_6$.

Trithionic acid, $\text{H}_2\text{S}_3\text{O}_6$.

Tetrathionic acid, $\text{H}_2\text{S}_4\text{O}_6$.

Pentathionic acid, $\text{H}_2\text{S}_5\text{O}_6$.

131. *Sulphuric Dioxide or Sulphurous Anhydride.*—

This is the only product of the combustion of sulphur in dry air or oxygen gas. It is most conveniently prepared by heating sulphuric acid with metallic mercury or copper clippings; a portion of the acid is decomposed, reducing it to sulphurous anhydride, which escapes as gas. $2\text{H}_2\text{SO}_4$ (sulphuric acid) + Cu = CuSO_4 (cupric sulphate) + $2\text{H}_2\text{O}$ + SO_2 (sulphurous anhydride). Another very simple method of preparing it consists in heating concentrated sulphuric acid with sulphur; a very regular evolution of sulphurous anhydride is thus obtained. It is a colorless gas, having the peculiar suffocating odor of burning brimstone; it instantly extinguishes flame, and is quite irrespirable. Its density is 2.21. At 0°F . (-17.8°C .), under the ordinary pressure of the atmosphere, the gas becomes a colorless, limpid liquid, very expansible by heat. Cold water dissolves more than thirty times its volume of the gas. The solution, which contains *hydric sulphite* or *sulphurous acid*, H_2SO_3 , may be kept unchanged if air is excluded, but access of oxygen gradually converts the sulphurous into sulphuric acid, although dry sulphurous anhydride and oxygen gases may remain in contact for any length of time without change. When sulphurous anhydride and aqueous vapor are passed into a vessel

cooled to below 17° or 21° F. (-8.3° or -6° C.), a crystalline body forms, which contains about 24.2 parts of SO_2 to 75.8 of H_2O .

One volume of SO_2 contains one volume of oxygen and half a volume of sulphur-vapor, condensed into one volume.

SO_2 has bleaching properties, and is used in the arts for bleaching woollen goods and straw. A piece of blue litmus-paper plunged into the moist gas is first reddened and then slowly bleached.

132. *Sulphuric Trioxide or Sulphuric Anhydride.*—This compound, SO_3 , may be formed directly by passing a dry mixture of sulphurous anhydride and oxygen gases over heated spongy platinum; or it may be obtained by distilling the most concentrated sulphuric acid with phosphoric anhydride, which abstracts the water and sets the sulphuric anhydride free. It is usually prepared, however, from the fuming oil of vitriol of Nordhausen, which may be regarded as a solution of SO_3 in sulphuric acid. On gently heating this liquid in a retort connected with a receiver cooled by a freezing mixture, the SO_3 distils over in great abundance, and condenses into beautiful white silky crystals, resembling those of asbestos. When thrown into water, it hisses like a red-hot iron, from the violence with which combination occurs; the product is sulphuric acid. When exposed to the air, even for a few moments, it liquefies by absorption of moisture.

133. *Hydric Sulphate or Sulphuric Acid.*—This compound, H_2SO_4 , has been known since the fifteenth century. There are two distinct processes by which it is at present prepared; namely, by the distillation of ferrous sulphate (copperas or green vitriol), and by the oxidation of sulphurous anhydride with nitric peroxide and oxide.

The first process is still carried on in some parts of Germany, especially in the neighborhood of Nordhausen in

Prussia, and in Bohemia. The ferrous sulphate, derived from the oxidation of iron pyrites, is deprived by heat of the greater part of its water of crystallization, and subjected to a high red heat in earthen retorts, to which receivers are fitted as soon as the acid begins to distil over. A part is decomposed by the very high temperature ; the remainder is driven off in vapor, which is condensed by the cold vessel, containing a very small quantity of water or common sulphuric acid. The product is a brown oily liquid of about 1.9 specific gravity, fuming in the air, and very corrosive. It is chiefly made for the purpose of dissolving indigo.

The second method, which is, perhaps, with the single exception mentioned, always followed as the more economical, depends upon the fact that, when sulphuric anhydride, nitric peroxide, and* water are present together in certain proportions, the SO_2 becomes oxidized at the expense of the nitric peroxide which, by the loss of one half of its oxygen, sinks to the condition of nitric oxide. A large and very long chamber is built of sheet-lead supported by timber framing ; on the outside, at one extremity, a small furnace or oven is constructed, having a wide tube leading into the chamber. In this, sulphur is kept burning, the flame of which heats a crucible containing a mixture of nitre and oil of vitriol. The floor of the chamber is covered with water, and a jet of steam is also introduced. Lastly, an exit is provided at the farther end of the chamber for the spent and useless gases. The effect of these arrangements is to cause a constant supply of sulphurous anhydride, atmospheric air, nitric acid vapor, and water in the state of steam, to be thrown into the chamber, there to mix and react upon each other. The nitric acid immediately gives up a part of its oxygen to the sulphurous anhydride, and is itself reduced to nitric peroxide ; it does not remain in this state, however, but suffers further deoxi-

dation until it becomes reduced to nitric oxide. That substance, in contact with free oxygen, absorbs a portion of the latter, and once more becomes peroxide, which is again destined to undergo deoxidation by a fresh quantity of sulphurous anhydride. A very small portion of nitric peroxide, mixed with atmospheric air and sulphurous anhydride, may thus in time convert an indefinite amount of the latter into sulphuric acid, by acting as a carrier between the oxygen of the air and the sulphurous anhydride. The presence of water is essential to this reaction.

We may thus represent the change: NO_2 (nitric peroxide) + SO_2 + H_2O = NO (nitric oxide) + H_2SO_4 (sulphuric acid).

Such is the simplest view that can be taken of the production of sulphuric acid in the leaden chamber; but the reaction may be more complex. When a little water is put at the bottom of a large glass globe, so as to keep the air moist within, and sulphurous anhydride and nitric peroxide are introduced by separate tubes, chemical action immediately begins, and after a little time a white crystalline matter is observed to condense on the sides of the vessel. This substance appears to be a compound of sulphuric acid, nitrous anhydride, and a little water. When thrown into water, it is resolved into sulphuric acid, nitric oxide, and nitric acid. This curious body is certainly very often produced in large quantity in the leaden chambers; but that its production is indispensable to the success of the process, and constant when the operation goes on well and the nitric peroxide is not in excess, may perhaps admit of doubt.

The water at the bottom of the chamber thus becomes loaded with sulphuric acid. When a certain degree of strength has been reached, the acid is drawn off and concentrated by evaporation, first in leaden pans, and afterwards in stills of platinum, until it attains a density (when

cold) of 1.84, or thereabouts ; it is then transferred to *carboys*, or large glass bottles fitted in baskets, for sale. In Great Britain this manufacture is one of great national importance, and is carried on to a vast extent.

The most concentrated sulphuric acid, or *oil of vitriol*, as it is often called, is a definite combination of 40 parts sulphuric anhydride, and 9 parts water. $\text{SO}_3 + \text{H}_2\text{O} = \text{H}_2\text{SO}_4$. It is a colorless oily liquid, having a specific gravity of about 1.85, of intensely acid taste and reaction. Organic matter is rapidly charred and destroyed by this substance. At the temperature of -26°C (-15°F .) it freezes ; at 327°C . (620°F .) it boils, and may be distilled without decomposition. Oil of vitriol has a most energetic attraction for water ; it withdraws aqueous vapor from the air, and when it is diluted with water great heat is evolved, so that the mixture always requires to be made with caution. Oil of vitriol is not the only definite compound of sulphuric anhydride and water ; three others are known to exist. When the fuming oil of vitriol of Nordhausen is exposed to a low temperature, a white crystalline substance separates, which contains half as much water as the common liquid acid. Then, again, a mixture of 98 parts of strong liquid acid and 18 parts of water congeals or crystallizes at a temperature above 0°C ., and remains solid even at 7.2°C . (45°F .). $\text{SO}_3 + 2\text{H}_2\text{O} = \text{H}_2\text{SO}_4 \cdot \text{H}_2\text{O}$. Lastly, when a very dilute acid is concentrated by evaporation in a vacuum over a surface of oil of vitriol, the evaporation stops when the sulphuric oxide and water bear to each other the proportion of 80 to 54. $\text{SO}_3 + 3\text{H}_2\text{O} = \text{H}_2\text{SO}_4 \cdot 2\text{H}_2\text{O}$.

When the vapor of sulphuric acid is passed over red-hot platinum, it is decomposed into oxygen and sulphurous anhydride. St. Claire Deville and Debray have recommended this process for the preparation of oxygen on the large scale, the sulphurous anhydride being easily separated by its solubility in water or alkaline solutions.

Sulphuric acid acts readily on basic oxides, converting them into sulphates. With the aid of heat it decomposes all salts containing acids more volatile than itself. The sulphates are a very important class of salts, many of them being extensively used in the arts. Most sulphates are soluble in water, but they are all insoluble in alcohol. The barium, calcium, strontium, and lead salts are insoluble, or very slightly soluble, in water, and are formed by precipitating a soluble salt of either of those metals with sulphuric acid, or a soluble metallic sulphate. Baric sulphate is quite insoluble in water; consequently sulphuric acid, or its soluble salts, may be detected with the greatest ease by solution of baric nitrate or chloride. A white precipitate is thereby produced which does not dissolve in nitric acid.

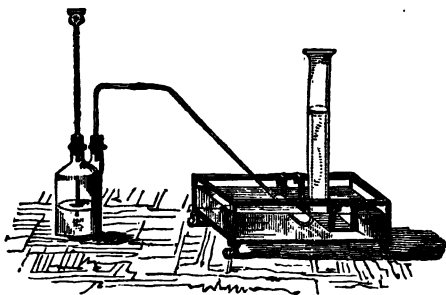
134. *Hydric Hyposulphite, or Hyposulphurous Acid.* — By digesting sulphur with a solution of potassic or sodic sulphite, a portion of that substance is dissolved, and the liquid, by slow evaporation, furnishes crystals of hyposulphite. $K_2SO_3 + S = K_2S_2O_3$. The acid itself is scarcely known, for it cannot be isolated; when muriatic acid is added to a solution of a hyposulphite, the acid of the latter is almost instantly resolved into sulphur, which precipitates, and hydric sulphite, easily recognized by its odor. In very dilute solution, however, it appears to remain undecomposed for some time. The most remarkable feature of the alkaline hyposulphites is their property of dissolving certain insoluble salts of silver, as the chloride, which has given them considerable importance in photography. They are also much used as *antichlores* (a name formed from *anti*, against, and *chlorine*) for removing the last traces of chlorine from bleached goods.

135. *Hydric Sulphide (Hydrosulphuric Acid, or Sulphuretted Hydrogen).* — There are two methods by which this important compound can be readily prepared; namely, by the action of dilute sulphuric acid upon ferrous sulphide,

and by the decomposition of antimonie trisulphide with muriatic acid. The first method yields it most easily, the second in the purest state.

Ferrous sulphide is put into a bottle arranged as in Figure 46, together with water, and oil of vitriol is added by the funnel, until the gas is copiously disengaged. It must

Fig. 46.



be collected over tepid water. The reaction is as follows :
 $\text{FeS (ferrous sulphide)} + \text{H}_2\text{SO}_4 = \text{H}_2\text{S (hydric sulphide)} + \text{FeSO}_4 \text{ (ferrous sulphate).}$

By the other plan, finely powdered antimonie trisulphide is put into a flask with a bent tube, and strong muriatic acid poured upon it. On the application of heat a double interchange occurs between the bodies present, hydric sulphide and antimonie trichloride being formed. Sb_2S_3 (antimonie trisulphide) $+ 6\text{HCl} = 3\text{H}_2\text{S} + 2\text{SbCl}_3$ (antimonie trichloride).

Hydric sulphide is a colorless gas, having the odor of putrid eggs ; it is most offensive when a mere trace is present in the air. It is not irritating, but, on the contrary, powerfully narcotic. When set on fire it burns with a blue flame, producing sulphurous anhydride when the supply of air is abundant, and depositing sulphur when the oxygen is deficient. Mixed with chlorine, it is instantly decomposed, with separation of all the sulphur.

This gas has a specific gravity of 1.171 referred to air, or 17 referred to hydrogen as unity.

A pressure of 17 atmospheres at 10° reduces it to the liquid form. Cold water dissolves its own volume of hydric sulphide, and the solution is often directed to be kept as a test ; it is so prone to decomposition, however, by the oxygen of the air, that it quickly spoils. A much better plan is to keep a little apparatus for generating the gas always at hand, and ready for use at a moment's notice. A small bottle or flask, to which a bit of bent tube is fitted by a cork, is supplied with a little ferrous sulphide and water ; when required for use a few drops of oil of vitriol are added, and the gas is at once evolved. The experiment completed, the liquid is poured from the bottle, replaced by a little clean water, and the apparatus is again ready for use.

Hydric sulphide is a frequent product of the putrefaction of organic matter, both animal and vegetable ; it occurs also in certain mineral springs. When accidentally present in the atmosphere of a room, it may be instantaneously destroyed by a small quantity of chlorine gas.

There are few reagents of greater value to the practical chemist than this substance ; when brought in contact with many metallic solutions it gives rise to precipitates, which are often exceedingly characteristic in appearance, and it frequently affords the means of separating metals from each other with the greatest precision and certainty. The precipitates spoken of are insoluble sulphides, formed by the mutual decomposition of the metallic oxides or chlorides and hydric sulphide, water or muriatic acid being produced at the same time. All the metals are, in fact, precipitated whose sulphides are insoluble in water and in dilute acids.*

* Arsenic and cadmium solutions thus treated give bright yellow precipitates, the former soluble, the latter insoluble, in ammoniac sul-

Hydric sulphide possesses the properties of an acid ; its solution in water reddens litmus-paper.

The best test for the presence of this compound is paper wetted with solution of plumbic acetate (sugar of lead). This salt is blackened by the smallest trace of the gas.

136. *Carbonic Disulphide (Bisulphide of Carbon)*. — A white porcelain tube is filled with pieces of charcoal which have been recently heated to redness in a covered crucible, and fixed across a furnace in a slightly inclined position. Into the lower extremity a tolerably wide tube is secured by the aid of a cork ; this tube bends downwards, and passes nearly to the bottom of a bottle filled with fragments of ice and a little water. The porcelain tube being heated to a bright redness, fragments of sulphur are thrown into the open end, which is then stopped by a cork. The sulphur melts, and becomes converted into vapor, which at that high temperature combines with the carbon, forming an exceedingly volatile compound, CS_2 , which is condensed by the ice and collects at the bottom of the vessel. This is collected and redistilled at a very gentle heat in a retort connected with a good condenser.

Carbonic disulphide is a transparent, colorless liquid of great refractive and dispersive power. Its density is 1.272, that of its vapor is 2.67. It boils at 43° , and emits vapor of considerable elasticity at common temperatures. It has a very repulsive odor.* When set on fire in the air it

phide ; tin-salts give a brown or a yellow precipitate, according as the metal is in the form of a stannous or a stannic salt, both soluble in ammoniac sulphide. Antimony solutions give an orange-red precipitate, soluble in ammoniac sulphide. Copper, lead, bismuth, mercury, and silver salts give dark-brown or black precipitates, insoluble in ammoniac sulphide ; gold and platinum salts, black precipitates, soluble in ammoniac sulphide.

* French chemists have recently (1869) devised a process for removing this odor. The disulphide is washed several times with distilled water, and allowed to remain for some 24 hours in contact with lime.

burns with a blue flame, forming carbonic and sulphurous anhydrides; and when its vapor is mixed with oxygen it becomes explosive. It freely dissolves sulphur, and by spontaneous evaporation deposits the latter in beautiful crystals; it also dissolves phosphorus, iodine, camphor, and caoutchouc, and mixes easily with oils. It is extensively used in the vulcanization of caoutchouc, and in the manufacture of gutta-percha, also for extracting bitumen from mineral substances, and oil from seeds.

Carbonic disulphide unites with metallic sulphides, forming salts called *sulphocarbonates*, which have the composition of carbonates in which the oxygen is replaced by sulphur.

SELENIUM.

137. *Its Properties, etc.* — This is a very rare substance, much resembling sulphur in its chemical relations, and found in association with that element in some few localities, or replacing it in certain metallic combinations, as in the plumbic selenide of Clausthal in the Hartz.

Selenium is a reddish-brown solid body, somewhat translucent, and having an imperfect metallic lustre. Its specific gravity, when rapidly cooled after fusion, is 4.3. At 100°, or a little above, it melts, and boils. It is insoluble in water, and exhales, when heated in the air, a peculiar and disagreeable odor, which has been compared to that of decaying horse-radish; it is insoluble in alcohol, but dissolves slightly in carbonic disulphide, from which solution it crystallizes.

138. *Hydric Selenide (Seleniatted Hydrogen).* — This substance, H_2Se , much resembles hydric sulphide, being a

It is then redistilled and received in a flask partly filled with copper turnings, which have been roasted to remove all fatty matter and afterwards reduced by hydrogen. The purified disulphide has no odor except a faint ethereal one. The lime becomes highly colored.

colorless gas, freely soluble in water, and decomposing metallic solutions like that substance ; insoluble selenides are thus produced. This gas is said to act very powerfully upon the lining membrane of the nose, exciting catarrhal symptoms, and destroying the sense of smell. It contains 79.4 parts selenium and 2 parts hydrogen.

TELLURIUM.

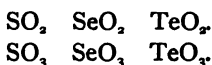
139. *Its Properties, etc.* — This element possesses many of the characters of a metal, but it bears so close a resemblance to selenium, both in its physical properties and its chemical relations, that it is most appropriately placed in the same group with that body. Tellurium is found in a few scarce minerals in association with gold, silver, lead, and bismuth, apparently replacing sulphur.

Tellurium has the color and lustre of silver ; by fusion and slow cooling it may be made to exhibit the form of rhombohedral crystals similar to those of antimony and arsenic. It is brittle, and a comparatively bad conductor of heat and electricity ; it has a density of 6.26, melts at a little below a red-heat, and volatilizes at a higher temperature. Tellurium burns when heated in the air, and is oxidized by nitric acid.

Tellurium forms a compound with hydrogen analogous to those formed by sulphur and selenium.

140. *The Oxygen Group.* — In oxygen, sulphur, selenium, and tellurium we have another remarkable family of elements, with the same gradation of physical and chemical properties as those of the chlorine group. The atomic weight of oxygen is 16, of sulphur 32, of selenium 80 (?), of tellurium 128. Here, as in the chlorine group, the chemical power of the elements diminishes as their atomic weights increase, oxygen, as a rule, being stronger than sulphur, sulphur than selenium, and selenium than tellurium.

An important characteristic of the elements of this group is their ability to form compounds with hydrogen which contain two atoms of H to one of the other element: H_2O , H_2S , H_2Se , H_2Te . There are two analogous oxides of the last three elements: —



NITROGEN OR TRIVALENT GROUP OF NON-METALS.

NITROGEN.

141. *Its Preparation.* — Nitrogen* constitutes about four fifths of the atmosphere, and enters into a great variety of combinations. It may be prepared by several methods. One of the simplest of these is to burn out the oxygen from a confined portion of air by phosphorus, or by a jet of hydrogen.

A small porcelain capsule is floated on the water of the pneumatic trough, and a piece of phosphorus is placed in it and set on fire. A bell-jar is then inverted over the whole. At first the heat causes expansion of the air of the jar, and a few bubbles are expelled, after which the level of the water rises considerably. When the phosphorus ceases to burn for want of oxygen, and time has been given for the phosphoric anhydride to settle and to be absorbed by the water, the nitrogen may be transferred to another vessel, and its properties examined.

Prepared in this way, nitrogen contains a little vapor of phosphorus, which gives its peculiar odor. A preferable

* The name *nitrogen* means *nitre-maker*. This element is sometimes called *azote*, from two Greek words, meaning *without life*. The symbol used by French chemists is Az.

method is to fill a porcelain tube with turnings of copper, or, still better, with the spongy metal obtained by reducing the oxide with hydrogen ; to heat this tube to redness, and then pass through it a slow stream of atmospheric air, the oxygen of which is entirely removed during its progress by the heated copper.

If chlorine gas be passed into solution of ammonia, the latter is decomposed ; the chlorine combines with the hydrogen, and the nitrogen is set free with effervescence. In this manner very pure nitrogen can be obtained. In making this experiment it is necessary to stop short of saturating or decomposing the whole of the ammonia ; otherwise there will be great risk of accident from the formation of the dangerous explosive compound, nitric chloride (107).

142. *Its Properties.* — Nitrogen is destitute of color, taste, and odor ; it is a little lighter than air, its density being, according to Dumas, 0.972. It is incapable of sustaining combustion or animal life, although, like hydrogen, it has no positive poisonous properties. It is, in fact, best characterized by negative properties.

143. *Compounds of Nitrogen and Oxygen.* — There are five distinct compounds of nitrogen and oxygen, thus named and constituted : —

Nitrous oxide,	N_2O
Nitric oxide,	N_2O_2 or NO
Nitrous anhydride,	N_2O_3
Nitric peroxide,	N_2O_4 or NO_2
Nitric anhydride,	N_2O_5

A comparison of these symbols will show that the quantities of oxygen which unite with a given quantity of nitrogen are to one another in the ratio of the numbers 1, 2, 3, 4, 5.

The third and fifth of the compounds in the table are capable of taking up the elements of water and of metallic

oxides to form salts called respectively *nitrites* and *nitrates*, the hydrogen salts being also called *hydric nitrite*, or *nitrous acid*, and *hydric nitrate*, or *nitric acid*. The other three oxides do not form salts. It will be convenient to commence the description of these compounds with the last on the list, as its salts, the nitrates, are the sources from which all the other compounds in the series are obtained.

144. *Nitric Anhydride*. — This compound was discovered in 1849 by Deville, who obtained it by exposing argentic nitrate, which may be regarded as a compound of nitric anhydride with silver and oxygen, to the action of chlorine gas. Chlorine and silver then combine, forming argentic chloride, which remains in the apparatus, while oxygen and nitric anhydride separate. The reaction is as follows: 2AgNO_3 (argentic nitrate) $+$ $\text{Cl}_2 = 2\text{AgCl}$ (argentic chloride) $+$ $\text{O} + \text{N}_2\text{O}_5$. The latter is a colorless substance, crystallizing in six-sided prisms, which melt at 30° and boil between 45° and 50° , when they begin to decompose. It sometimes explodes spontaneously. It dissolves in water with great rise of temperature, forming *hydric nitrate* or *nitric acid*.

145. *Hydric Nitrate or Nitric Acid*. — In certain parts of India, and in other hot, dry climates where rain is rare, the surface of the soil is occasionally covered by a saline efflorescence, like that sometimes seen on newly plastered walls. This substance collected, dissolved in hot water, and crystallized from the filtered solution, furnishes the highly important salt known in commerce as *nitre* or *saltpetre*, and consisting of *potassic nitrate*. To obtain nitric acid equal weights of powdered nitre and strong sulphuric acid are put into a glass retort, and heated. A flask, cooled by a wet cloth, is used as a receiver. No luting of any kind must be used.

The reaction consists in an interchange between the potassium of the nitre and half the hydrogen of the sulphuric

acid, whereby there are formed hydric nitrate, which distils over, and acid potassic sulphate, which remains in the retort. KNO_3 (nitre) + $\text{H}_2\text{SO}_4 = \text{HNO}_3$ (hydric nitrate) + HKSO_4 (acid potassic sulphate).

In the manufacture of nitric acid on the large scale, the glass retort is replaced by a cast-iron cylinder, and the receiver by a series of earthen condensing vessels connected by tubes. Sodid nitrate, found native in Peru, is now generally substituted for potassic nitrate.

Nitric acid thus obtained has a specific gravity of from 1.5 to 1.52; it has a golden-yellow color, due to nitrous anhydride or nitric peroxide, which is held in solution, and, when the acid is diluted with water, gives rise by its decomposition to nitric oxide. Nitric acid is exceedingly corrosive, staining the skin deep-yellow, and destroying it. Poured upon red-hot powdered charcoal, it causes vivid combustion; and when added to warm oil of turpentine it sets it on fire.

Pure nitric acid, in its most concentrated form, is obtained by mixing the above with about an equal quantity of strong sulphuric acid, redistilling, collecting apart the first portion which comes over, and exposing it in a vessel slightly warmed and sheltered from the light to a current of dry air made to bubble through it, which completely removes the nitrous acid. In this state the product is as colorless as water; it has the sp. gr. 1.517 at 15.5° (60° F.), boils at 84.5° (184° F.), and consists of 54 parts nitric anhydride and 9 parts water. Although nitric acid in a more dilute form acts very violently upon many metals, and upon organic substances generally, this is not the case with the most concentrated acid. Even at a boiling heat, it refuses to attack iron or tin; and its mode of action on starch and similar substances is quite peculiar and very much less energetic than that of an acid containing more water.

The nitrates form a very extensive and important group of salts, which are remarkable for being all soluble in water.

Nitric acid has been formed in small quantity by passing a series of electric sparks through a portion of air in contact with water or an alkaline solution. The amount of acid so formed after many hours is very minute ; still it is not impossible that powerful discharges of atmospheric electricity may sometimes occasion a trifling production of nitric acid in the air. A very minute quantity of nitric acid is also produced by the combustion of hydrogen and other substances in the atmosphere ; it is also formed by the oxidation of ammonia.

The best method for the detection of nitric acid is the following. The substance to be examined is boiled with a small quantity of water, and the solution cautiously mixed with an equal volume of concentrated sulphuric acid ; the liquid is then allowed to cool, and a strong solution of ferrous sulphate carefully poured upon it, so as to form a separate layer. If large quantities of nitric acid are present, the surface of contact, first, and then the whole of the liquid, becomes black. If but small quantities of nitric acid are present, the liquid becomes reddish-brown or purple. The ferrous sulphate reduces the nitric acid to nitric oxide, which, dissolving in the solution of ferrous sulphate, imparts to it a dark color.

146. *Nitrous Oxide or Laughing Gas.*—When solid ammoniac nitrate is heated in a retort or flask,* it is resolved

* Florence oil-flasks, which may be purchased for a trifling sum, are very useful vessels for chemical purposes, and often supersede retorts or other expensive apparatus. They are rendered still more valuable by cutting the neck smoothly round with a hot iron, softening it in the flame of a good Argand gas-lamp, and then turning over the edge so as to form a lip, or border. The neck will then bear a tightly fitting cork without risk of splitting.

into water and nitrous oxide. NH_4NO_3 (ammonic nitrate) $= 2\text{H}_2\text{O} + \text{N}_2\text{O}$.

Nitrous oxide is a colorless, transparent, and almost odorless gas, of distinctly sweet taste. Its specific gravity is 1.525. It supports the combustion of a taper or of phosphorus with almost as much energy as pure oxygen. It is easily distinguished, however, from that gas by its solubility in cold water, which dissolves nearly its own volume. Hence it is necessary to use tepid water in the pneumatic trough or gas-holder; otherwise great loss of gas will ensue. Nitrous oxide has been liquefied, but with difficulty; it requires, at 45°F. (7.2°C.), a pressure of 50 atmospheres. The liquid, when exposed under the bell-glass of the air-pump, is rapidly converted into a snow-like solid. When mixed with an equal volume of hydrogen, and fired by the electric spark, it explodes with violence, and liberates its own measure of nitrogen. Every two volumes of the gas must consequently contain two volumes of nitrogen and one volume of oxygen, the whole being condensed one third, — a constitution resembling that of vapor of water.

The most remarkable property of this gas is its intoxicating power upon the animal system. If quite pure, or merely mixed with atmospheric air, it may be respired for a short time without danger. The effect is very transient, and is not followed by depression.

147. *Nitric Oxide.* — Clippings or turnings of copper are put into the apparatus employed for preparing hydrogen (Figure 46), together with a little water, and nitric acid is added by the funnel until brisk effervescence is excited. The gas may be collected over cold water, as it is not sensibly soluble.

The reaction is a simple deoxidation of some of the nitric acid by the copper; the metal is oxidized, and the oxide so formed is dissolved by another portion of the

acid. Nitric acid is very prone to act thus upon certain metals.

The gas obtained in this manner is colorless and transparent; in contact with air or oxygen gas it produces deep-red fumes,* which are readily absorbed by water. It is thus distinguished from all other gaseous bodies. A lighted taper plunged into the gas is put out; lighted phosphorus, however, burns in it with great brilliancy.

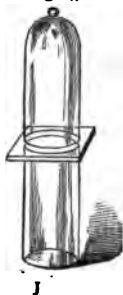
The specific gravity of this compound is 1.039. It contains equal measures of oxygen and nitrogen gases united without condensation. When this gas is passed into the solution of a ferrous salt, it is absorbed in large quantity, and a deep-brown, or nearly black liquid produced, which seems to be a definite compound of the two substances. The compound is again decomposed by boiling.

148. *Nitrous Anhydride*. — When four measures of nitric oxide are mixed with one measure of oxygen, and the gases, perfectly dry, are exposed to a temperature of -18° , they condense to a thin mobile blue liquid, which emits orange-red vapors. This is nitrous anhydride.

It is obtained sufficiently pure for most purposes by pouring concentrated nitric acid on lumps of arsenious acid, and gently warming the mixture, in order to start the reaction. Nitrous anhydride is then evolved as an orange-red gas, arsenic acid remaining behind.

* Invert a jar of oxygen or air over a jar of nitric oxide, and the two gases on mixing become of a cherry-red color. The apparatus shown in Figure 47 is convenient for this experiment. Fill the bell with oxygen, and the jar with nitric oxide. The jar should be closed with a plate and set on the table, and the bell of oxygen set on the plate covering the jar. When the experiment is to be tried the plate should be drawn out, and the mouths of the bell and jar allowed to come together.

Fig. 47.



Nitrous anhydride is decomposed by water, being converted into nitric acid and nitric oxide. $3\text{N}_2\text{O}_3 + \text{H}_2\text{O} = 2\text{HNO}_3 + 2\text{N}_2\text{O}_4$. For this reason it cannot be made to unite directly with metallic oxides; potassic nitrite may, however, be prepared by fusing potassic nitrate, whereby part of its oxygen is driven off; and many other salts of nitrous acid may be obtained by indirect means.

149. *Nitric Peroxide*. — This is the principal constituent of the deep-red fumes always produced when nitric oxide escapes into the air.

When carefully dried plumbic nitrate is exposed to heat in a retort of hard glass, it is decomposed, plumbic oxide remaining behind, while a mixture of oxygen and nitric peroxide is evolved. By surrounding the receiver with a very powerful freezing mixture, the latter is condensed in transparent crystals, or if the slightest trace of moisture is present, as a colorless liquid, which acquires a yellow and ultimately a red tint as the temperature rises. At 27.8° it boils, giving off its well-known red vapor, the intensity of the color of which is greatly augmented by elevation of temperature. Its vapor is absorbed by strong nitric acid, which thereby acquires a yellow or red tint passing into green, then into blue, and afterwards disappearing altogether on the addition of successive portions of water. The deep-red fuming acid of commerce, called *nitrous acid*, is simply nitric acid impregnated with nitric peroxide.

Nitric peroxide is decomposed by water at very low temperatures in such a manner as to yield nitric and nitrous acids ($\text{N}_2\text{O}_4 + \text{H}_2\text{O} = \text{HNO}_3 + \text{HNO}_2$); but when added to excess of water at ordinary temperatures it yields nitric acid, and the products of decomposition of nitrous acid; namely, nitric acid and nitric oxide. In like manner, when passed into alkaline solutions, it forms a nitrate and a nitrite of the alkali-metal; but it has been also supposed to unite, directly, under certain circumstances, with metal-

lic oxides, — plumbic oxide, for example, — forming definite crystalline salts, and has hence been called *hyponitric acid*; but it is most probable that these salts are compounds of nitrates and nitrites.

150. *Compounds of Nitrogen and Metals.* — Nitrogen appears to combine, under favorable circumstances, with metals. When iron is heated to redness in an atmosphere of ammonia, it becomes brittle and crystalline, and shows an increase in weight, said to vary from 6 to 12 per cent; while, according to other observers, the physical characters of the metal are changed without sensible alteration of weight. By heating copper in ammonia no compound of nitrogen with copper is produced. But when ammonia is passed over copper oxide heated to 300° water is formed, and a soft brown powder produced, which, when heated further, evolves nitrogen, and leaves metallic copper. The same effect is produced by the contact of strong acids. A similar compound of chromium with nitrogen appears to exist.

151. *Ammonia.* — When powdered sal-ammoniac is mixed with moist slaked lime, and gently heated in a glass flask, a large quantity of gaseous matter is disengaged, which must be collected over mercury, or by displacement.

Ammonia gas thus obtained is colorless; it has a strong pungent odor, and possesses in an eminent degree those properties to which the term *alkaline* is applied; that is to say, it turns the yellow color of turmeric to brown, that of reddened litmus to blue, and combines readily with acids, neutralizing them completely. By these reactions it is easily distinguished from all other bodies possessing the same physical characters. Under a pressure of 6.5 atmospheres at 15.5° , ammonia condenses to the liquid form. Water dissolves about 700 times its volume of this gas, forming a solution which has long been known under the

name of *aqua ammonia*.* The solution is decomposed by chlorine, sal-ammoniac being formed, and nitrogen set free.

Ammonia has a density of 0.589. It cannot be formed by the direct union of its elements. The great sources of ammonia are the nitrogenized compounds of the animal and vegetable kingdoms, which, when left to putrefactive change, or subjected to destructive distillation, almost invariably give rise to this substance.

Solution of ammonia is a very valuable reagent, and is employed in a great number of chemical operations, for some of which it is necessary to have it perfectly pure. The best mode of preparation is the following:—

Equal weights of sal-ammoniac and quicklime are taken; the lime is slaked in a covered basin, and the salt reduced to powder. These are mixed and introduced into the flask employed in preparing solution of muriatic acid, together with just enough water to damp the mixture, and cause it to aggregate into lumps; the rest of the apparatus is arranged exactly as in the former case (see Figure 41, page 99, and the accompanying description). The reaction in the process is as follows: $2\text{H}_4\text{NCl} + \text{CaO} = 2\text{H}_3\text{N} + \text{CaCl}_2 + \text{H}_2\text{O}$.

* A concentrated solution of ammonia has recently been applied by M. Carré for producing intense cold (for the manufacture of ice). The apparatus used for this purpose consists of two strong iron cylinders connected by tubes, the one cylinder containing the solution of ammonia, the other being empty, and the whole apparatus being perfectly air-tight. The empty cylinder is now cooled with water, and the other cylinder is gently warmed. The ammonia escapes from the solution, and is condensed by its own pressure in the cooled cylinder. If the source of heat be now removed, the liquefied ammonia is again absorbed by the water, and the heat necessary for its transformation into vapor being taken from the iron vessel, the water surrounding it is converted into ice; by this process the temperature may be reduced to $-15^\circ\text{C. (+5}^\circ\text{F.)}$.

PHOSPHORUS.

151. *Its Preparations, etc.* — Phosphorus in the state of phosphoric acid is contained in the old unstratified rocks, and in the lavas of modern origin. As these disintegrate and crumble down into fertile soil, the phosphates pass into the organism of plants, and ultimately into the bodies of the animals, to which these latter serve for food. The earthy phosphates play a very important part in the structure of the animal frame, by giving stiffness and inflexibility to the bony skeleton.

Phosphorus was discovered in 1669 by Brandt, of Hamburg. It is now made from bones. Thoroughly calcined bones are reduced to powder, and mixed with two thirds of their weight of sulphuric acid diluted with a considerable quantity of water; this mixture, after standing some hours, is filtered, and the nearly insoluble calcic sulphate is washed. The liquid is then evaporated to a sirupy consistence, mixed with charcoal powder, and the drying completed in an iron vessel exposed to a high temperature. It is then transferred to a stoneware retort, to which a wide, bent tube is luted, dipping a little way into the water contained in the receiver. A narrow tube serves to give issue to the gases, which are conveyed to a chimney. This manufacture is now conducted on a very large scale, enormous quantities of phosphorus being used for the apparently trifling article of friction-matches.

152. *Its Properties.* — Phosphorus, when pure, very much resembles in appearance imperfectly bleached wax, and is soft and flexible at common temperatures. Its density is 1.77, and that of its vapor 4.35, air being unity, or 62 referred to hydrogen as unity. It melts at 44° , and boils at 280° . By slowly cooling melted phosphorus well-formed dodecahedrons are sometimes obtained. It is insoluble in water, and is usually kept immersed in that liquid, but dis-

solves in oils, in native naphtha, and especially in carbonic disulphide. When set on fire in the air it burns with a bright flame, generating phosphoric anhydride. Phosphorus is exceedingly inflammable; it sometimes takes fire by the heat of the hand, and demands great care in its management; a blow or hard rub will very often kindle it. A stick of phosphorus held in the air always appears to emit a whitish smoke, which in the dark is luminous. This effect is chiefly due to a slow combustion which the phosphorus undergoes by the oxygen of the air. It is singular that the slow oxidation of phosphorus may be entirely prevented by the presence of a small quantity of olefiant gas, or the vapor of ether, or some essential oil; phosphorus may even be distilled in an atmosphere containing vapor of oil of turpentine in considerable quantity. Neither does the action go on in pure oxygen,—at least, at the temperature of 15.5° ,—which is very remarkable; but if the gas be rarefied, or diluted with nitrogen, hydrogen, or carbonic acid, oxidation begins.

A very remarkable modification of this element is known by the name of *amorphous phosphorus*. It was discovered by Schrötter, and may be made by exposing common phosphorus for fifty hours to a temperature of from 240° to 250° , in an atmosphere which is unable to act chemically upon it. At this temperature it becomes red and opaque, and insoluble in carbonic disulphide, whereby it may be separated from ordinary phosphorus. It may be obtained in compact masses when common phosphorus is kept for eight days at a constant high temperature. It is a coherent, reddish-brown, infusible substance, of specific gravity between 2.089 and 2.106. It does not become luminous in the dark until its temperature is raised to about 200° , nor has it any tendency to combine with the oxygen of the air. When heated to 260° it is reconverted into ordinary phosphorus.

153. *Compounds of Phosphorus and Oxygen.* — When phosphorus is melted beneath the surface of hot water, and a stream of oxygen gas forced upon it from a bladder, combustion ensues, and the phosphorus is converted in great part into a brick-red powder, which was formerly believed to be a peculiar oxide of phosphorus; but Schrötter has shown that it is a mixture, consisting chiefly of amorphous phosphorus.

There are two definite oxides of phosphorus, in which the quantities of oxygen united with the same quantity of phosphorus are to one another as 3 to 5; viz.:—

Phosphoric trioxide, or phosphorous anhydride, P_2O_3 ,
 “ pentoxide, “ phosphoric “ P_2O_5 .

Both these are acid oxides, uniting with water and metallic oxides to form salts, called *phosphites* and *phosphates* respectively; the hydrogen salts being also called *phosphorous* and *phosphoric acid*. There is also another oxygen-acid of phosphorus, containing a smaller proportion of oxygen, H_3PO_2 , called *hypophosphorous acid*, to which there is no corresponding anhydride.

154. *Phosphorous Anhydride.* — This is formed by the slow combustion of phosphorus in the atmosphere; or by burning that substance by means of a very limited supply of dry air, in which case it presents the aspect of a white powder. *Phosphorous acid*, H_3PO_3 , is most conveniently prepared by adding water to the phosphoric trichloride, when mutual decomposition takes place, the oxygen of the water being transferred to the phosphorus, generating phosphorous acid, and its hydrogen to the chlorine, giving rise to muriatic acid. $PCl_3 + 3H_2O = H_3PO_3 + 3HCl$. By evaporating the solution to the consistence of sirup, the muriatic acid is expelled, and the residue, on cooling, crystallizes.

Phosphorous acid is very deliquescent and very prone to

attract oxygen and pass into phosphoric acid. When heated in a close vessel, it is resolved into phosphoric acid and pure hydric phosphide.

The phosphites are of little importance.

155. *Phosphoric Anhydride*. — When phosphorus is burned under a bell-jar by the aid of a copious supply of dry air, snow-like phosphoric anhydride is produced in great quantity. This substance has as much attraction for water as sulphuric anhydride; exposed to the air for a few moments, it deliquesces to a liquid, and when thrown into water combines with the latter with explosive violence. The water then taken up cannot again be separated.

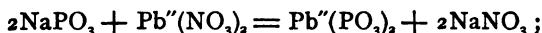
Phosphoric anhydride is readily volatilized, and may be sublimed by the heat of an ordinary spirit-lamp. The acid may be fused in a platinum crucible at a red heat; at this temperature it evolves considerable quantities of vapor, but is still far from its boiling point. It is a very powerful acid; being less volatile than sulphuric acid, it expels the latter at higher temperatures, although it is displaced by sulphuric acid at the common temperature. Its solution has an intensely sour taste, and reddens litmus-paper; it is not poisonous.

156. *Hydric Phosphate or Phosphoric Acid*. — There are three modifications of phosphoric acid: one being *monobasic*, the second *tribasic*, and the third *tetrabasic*.

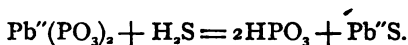
Hydric phosphide, H_3P , burnt in air or oxygen gas, takes up four atoms of oxygen, and forms *trihydric phosphate* or *tribasic phosphoric acid*, H_3PO_4 . This acid forms three distinct classes of metallic salts. With sodium, for example, it forms the three salts NaH_2PO_4 , Na_2HPO_4 , and Na_3PO_4 , the first two of which, still containing replaceable hydrogen, are *acid* salts, while the third is the *normal* or *neutral* salt.

If now the *monosodic phosphate*, NaH_2PO_4 , be heated to redness, it gives off one molecule of water, and leaves an

anhydrous monosodic phosphate, NaPO_3 , the aqueous solution of which, when treated with plumbic nitrate, yields a lead-salt of corresponding composition; thus,



and this lead-salt, decomposed by hydric sulphide, yields a monohydric acid having the composition HPO_3 , possessing properties quite distinct from those of the trihydric acid above mentioned:—



The trihydric acid which is produced by the oxidation of phosphorus, and by the decomposition of the ordinary native phosphates, is called *orthophosphoric acid*, or *ordinary phosphoric acid*; the monohydric acid is called *metaphosphoric acid*.

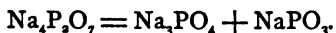
Both are soluble in water, and the former may be produced by the action of boiling water, the latter by that of cold water, on phosphoric anhydride. They are easily distinguished from one another by their reactions with albumen and with argentic nitrate. Metaphosphoric acid coagulates albumen, and gives a white precipitate with argentic nitrate; whereas orthophosphoric acid does not coagulate albumen, and gives no precipitate, or a very slight one, with argentic nitrate, till it is neutralized with an alkali, in which case a yellow precipitate is formed.

Metaphosphoric acid and its salts differ from orthophosphoric acid and the orthophosphates by the want of one or two atoms of water or base; thus:—

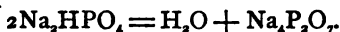
Metaphosphates.		Orthophosphates.	
HPO_3	=	H_3PO_4	— H_2O .
NaPO_3	=	NaH_2PO_4	— H_2O .
$\text{Ba}''(\text{PO}_3)_2$	=	$\text{Ba}''\text{H}_4(\text{PO}_4)_2$	— $2\text{H}_2\text{O}$.
AgPO_3	=	Ag_3PO_4	— Ag_2O .
$\text{Pb}''(\text{PO}_3)_2$	=	$\text{Pb}''_3(\text{PO}_4)_2$	— $2\text{Pb}''\text{O}$.

Accordingly, we find that metaphosphates and orthophosphates are convertible one into the other by the loss or gain of one or two atoms of water or metallic base.

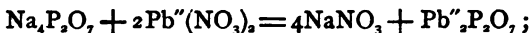
Intermediate between orthophosphates and metaphosphates, there are at least three distinct classes of salts, the most important of which are the *pyrophosphates* or *paraphosphates*, which may be derived from the tetrahydric or quadribasic acid, $\text{H}_4\text{P}_2\text{O}_7$; the normal sodium salt, for example, being $\text{Na}_4\text{P}_2\text{O}_7$, the normal lead salt, $\text{Pb}''_2\text{P}_2\text{O}_7$, &c. These salts may be viewed as compounds of orthophosphate and metaphosphate. Thus,



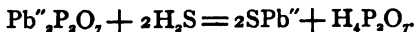
Sodic pyrophosphate is produced by heating disodic orthophosphate to redness, a molecule of water being then given off:—



The aqueous solution of this salt yields insoluble pyrophosphates with lead and silver salts; thus with plumbic nitrate,



and plumbic pyrophosphate decomposed by hydric sulphide yields hydric pyrophosphate or pyrophosphoric acid:—



Pyrophosphoric acid is distinguished from metaphosphoric acid by not coagulating albumen and not precipitating neutral solutions of barium or silver salts, and from orthophosphoric acid by producing a white instead of a yellow precipitate with argentic nitrate.

Pyrophosphates are easily converted into metaphosphates and orthophosphates, and *vice versa*, by addition or subtraction of water or a metallic base.

There are few bodies that are more interesting to the chemist than phosphoric anhydride on account of the

changes which its compounds undergo by the action of heat.

157. *Hydric Phosphide or Phosphoretted Hydrogen.* — This body is analogous in some of its chemical relations to ammoniacal gas ; its alkaline properties are, however, much weaker.

It may be obtained in a state of purity by heating phosphorous acid in a small retort, the acid being then resolved into hydric phosphide, and phosphoric acid. $4\text{H}_3\text{PO}_3 = \text{H}_3\text{P}$ (hydric phosphide) $+ 3\text{H}_3\text{PO}_4$.

Thus obtained the gas has a density of 1.24.

H_3P may be produced by boiling together, in a retort of small dimensions, caustic potash or slaked lime, water, and phosphorus.* In the reaction which ensues the water is decomposed, and both its elements combine with the phosphorus. $\text{P}_8 + 3\text{CaH}_2\text{O}_2$ (lime) $+ 6\text{H}_2\text{O} = 2\text{H}_3\text{P} + 3\text{CaH}_4\text{P}_2\text{O}_4$ (calcic hypophosphite).

The hydric phosphide thus prepared has the singular property of spontaneous inflammability when admitted into the air or into oxygen gas. With the latter the experiment is very beautiful, but requires caution ; the bubbles should be admitted singly. When kept over water for some time the gas loses this property, without otherwise suffering any appreciable change ; but if dried by calcic chloride, it may be kept unaltered for a much longer time. M. Paul Thénard has shown that the spontaneous combustibility of the gas arises from the presence of the vapor of a liquid hydric phosphide, which can be procured in small quantity by conveying the gas produced by the action of water on

* Use a tubulated retort. Fill it nearly full of water, put in a small piece of phosphorus, and let the mouth of the retort dip under water. Heat the retort until the water in it boils, and then drop in a stick of caustic potash through the tubulature. The water is boiled first in order to drive out the air from the retort, so that the hydric phosphide may not take fire inside, and thus cause an explosion.

calcic phosphide through a tube cooled by a freezing mixture. This substance forms a colorless liquid of high refractive power and very great volatility. It does not freeze at 0° F. (-17.8° C.). In contact with air it inflames instantly, and its vapor in very small quantity communicates spontaneous inflammability to pure hydric phosphide, and to all other combustible gases. It is decomposed by light into gaseous hydric phosphide, and a solid phosphide which is often seen on the inside of jars containing gas which, by exposure to light, has lost the property of spontaneous inflammation. Strong acids occasion its instantaneous decomposition. It is as unstable as hydric dioxide. It is to be observed that the pure hydric phosphide gas itself becomes spontaneously inflammable if heated to the temperature of boiling water.*

158. *Compounds of Phosphorus with Chlorine.*—Phosphorus forms two chlorides, analogous in composition to the oxides, the quantities of chlorine combined with the same quantity of phosphorus being to one another in the proportion of 3 to 5.

Phosphoric Trichloride or *Phosphorous Chloride*, PCl_3 , is prepared by gently heating phosphorus in dry chlorine gas, the phosphorus being in excess, or by passing the vapor of phosphorus over fragments of calomel (mercurous chloride) contained in a glass tube, and strongly heated. It is a colorless, thin liquid, which fumes in the air, and has a powerful and offensive odor. Its specific gravity is 1.45. Thrown into water, it sinks to the bottom of that liquid, and is slowly decomposed, yielding phosphorous acid and muriatic acid. $\text{PCl}_3 + 3\text{H}_2\text{O} = 3\text{HCl} + \text{H}_3\text{PO}_3$.

Phosphoric Pentachloride or *Phosphoric Chloride*, PCl_5 , is formed when phosphorus is burned in excess of chlorine.

* According to M. Paul Thénard, the liquid hydric phosphide contains H_2P and the solid HP_2 . The gas is represented by the formula H_2P .

Pieces of phosphorus are introduced into a large tubulated retort, which is then filled with dry chlorine gas. The phosphorus takes fire, and burns with a pale flame, forming a white volatile crystalline sublimate, which is the pentachloride. It may be obtained in larger quantity by passing a stream of dry chlorine gas into the preceding liquid trichloride, which becomes gradually converted into a solid crystalline mass. PCl_5 is decomposed by water, yielding phosphoric and muriatic acids. $\text{PCl}_5 + 4\text{H}_2\text{O} = 5\text{HCl} + \text{H}_3\text{PO}_4$.

159. *Compounds of Phosphorus with Sulphur.*—When ordinary phosphorus and sulphur are heated together in the dry state, or melted together under water, combination takes place between them, attended with vivid combustion and often with violent explosion. When amorphous phosphorus is used the reaction is not explosive, though still very rapid.

Six compounds of sulphur and phosphorus have been prepared :—

Hemisulphide,	P_4S .
Monosulphide,	P_2S .
Sesquisulphide,	P_4S_3 .
Trisulphide,	P_2S_3 .
Pentasulphide,	P_2S_5 .
Dodecasulphide,	P_2S_{12} .

The fourth and fifth are analogous to phosphorous and phosphoric anhydrides respectively. They may all be formed by heating the two bodies together in the required proportions; but the trisulphide and pentasulphide are more easily prepared by warming the monosulphide with additional proportions of sulphur. Moreover, the two lower sulphides exhibit isomeric modifications, each being capable of existing as a colorless liquid and as a red solid. The mono-, tri-, and pentasulphides unite with metallic sulphides, forming sulphur-salts.

ANTIMONY.

160. *Its Properties, etc.* — This important element (formerly considered a metal) is found chiefly in the state of sulphide. This is freed by fusion from earthy impurities, and is afterwards decomposed by heating with metallic iron or potassic carbonate, which retains the sulphur. Antimony has a bluish-white color and strong lustre; it is extremely brittle, being reduced to powder with the utmost ease. Its specific gravity is 6.8; it melts at a temperature just short of redness, and boils and volatilizes at a white heat. It has always a distinct crystalline, platy structure, but by particular management it may be obtained in crystals, which are rhombohedral.* Antimony is not oxidized by the air at common temperatures; when strongly heated it burns with a white flame, producing oxide, which is often deposited in beautiful crystals. It is dissolved by hot muriatic acid, with evolution of hydrogen and production of chloride. Nitric acid oxidizes it to antimonious acid, which is insoluble in that liquid.

Antimony forms two classes of compounds, the *antimonious* compounds, in which it is trivalent, as $\text{Sb}^{\text{III}}\text{Cl}_3$, $\text{Sb}^{\text{III}}_2\text{O}_3$, $\text{Sb}^{\text{III}}_2\text{S}_3$, etc., and the *antimonic* compounds, in which it is quinquevalent, as $\text{Sb}^{\text{V}}\text{Cl}_5$, $\text{Sb}^{\text{V}}_2\text{O}_5$, $\text{Sb}^{\text{V}}_2\text{S}_5$, etc.

161. *Chlorides of Antimony.* — The *trichloride* or *antimonious chloride*, SbCl_3 , formerly called *butter of antimony*, is produced when hydric sulphide is prepared by the action of strong muriatic acid on antimonious sulphide. It is very deliquescent; it dissolves in strong muriatic acid with-

* "On electrolysing a solution of 1 part of tartar-emetic in 4 parts of antimonious chloride by a small battery of two elements, antimony forming the positive and metallic copper the negative pole, crusts of antimony are obtained which possess the remarkable property of exploding and catching fire when cracked or broken." — GORE, *Proceedings of the Royal Society*, ix. 70.

out decomposition, and the solution poured into water gives rise to a white bulky precipitate, which, after a short time, becomes highly crystalline, and assumes a pale fawn-color. This is the old *powder of Algaroth*; it is a compound of trichloride and trioxide of antimony. Alkaline solutions extract the chloride and leave the oxide. Finely powdered antimony thrown into chlorine gas takes fire.

The *pentachloride* or *antimonic chloride*, SbCl_5 , is formed by passing a stream of chlorine gas over gently heated antimony; a mixture of the two chlorides results, which may be separated by distillation. The pentachloride is a colorless volatile liquid, which forms a crystalline compound with a small portion of water, but is decomposed by a larger quantity into antimonious and muriatic acids.

162. *Hydric Antimonide or Antimonetted Hydrogen.* — When zinc is put into a solution of antimonious oxide, and sulphuric acid added, part of the hydrogen combines with the antimony, and the resulting gas burns with a greenish flame, giving rise to white fumes of antimonious oxide. When the gas is conducted through a red-hot glass tube of narrow dimensions, or burned with a limited supply of air, as when a cold porcelain surface is pressed into the flame, antimony is deposited. On passing a current of the gas through a solution of argentic nitrate, a black precipitate is obtained, containing Ag_3Sb ; from the formation of this compound it is inferred that the gas has the composition H_3Sb , analogous to H_3N , H_3P , etc.

163. *Compounds of Antimony and Oxygen.* — Antimony forms two oxides, Sb_2O_3 and Sb_2O_5 , analogous to the chlorides, the first being a basic and the second an acid oxide; also an intermediate neutral oxide, Sb_2O_4 .

The *trioxide*, or *antimonious oxide*, Sb_2O_3 , occurs native, though rarely, as *valentinite* or *white antimony*, in shining white trimetric crystals; also as *senarmontite* in regular octohedrons; it is therefore *dimorphous* (49). When

boiled with cream of tartar (acid potassic tartrate), it is dissolved, and the solution yields on evaporation crystals of *tartar-emetic*, which is almost the only antimonious salt that can bear admixture with water without decomposition.

Antimonious oxide likewise acts as a feeble acid, forming salts called *antimonites*, which, however, are very unstable.

The *pentoxide* or *antimonic oxide*, Sb_2O_5 , is formed as an insoluble hydrate when strong nitric acid is made to act upon antimony; and, on exposing this hydrate to a heat short of redness, it yields the anhydrous pentoxide as a pale straw-colored powder, insoluble in water and acid. It is decomposed by a red-heat.

Hydrated antimonic oxide is likewise obtained by decomposing antimonic chloride with an excess of water, muriatic acid being formed at the same time. The hydrated oxides, or acids, produced by the two processes mentioned differ in many of their properties, and especially in their deportment with bases. The acid produced by nitric acid, called *antimonic acid*, is monobasic. The other, called *metantimonic acid*, is dibasic. Among the metantimonates an acid potassic salt, $\text{KSbO}_3 \cdot 7\text{H}_2\text{O}$, is to be particularly noticed as yielding a precipitate with sodium salts; it is, indeed, the only reagent which precipitates sodium.

164. *Compounds of Antimony and Sulphur.*—The *trisulphide* or *antimonious sulphide*, Sb_2S_3 , occurs native as a lead-gray, brittle substance, having a radiated crystalline texture, and is easily fusible. It may be prepared artificially by melting together antimony and sulphur. When a solution of tartar-emetic is precipitated by hydric sulphide, a brick-red precipitate falls, which is the same substance combined with a little water. If the precipitate be dried and gently heated, the water may be expelled without other change of color than a little darkening, but at a higher temperature it assumes the color and aspect of the

native sulphide. This remarkable change probably indicates a passage from the amorphous to the crystalline condition.

The *pentasulphide* or *antimonic sulphide*, Sb_2S_5 , formerly called *sulphur auratum*, is also a sulphur acid, forming salts called *sulph-antimonates*, most of which have the composition M_3SbS_4 , analogous to the normal orthophosphates. (156.)

165. *Uses of Antimony and its Compounds.* — Besides its application to medicine, antimony is of great importance in the arts, inasmuch as, in combination with lead, it forms *type metal*. This alloy expands at the moment of solidifying, and takes an exceedingly sharp impression of the mould. It is remarkable that both its constituents shrink under similar circumstances, and make very bad castings.

Britannia metal is an alloy of 9 parts tin and 1 part antimony, frequently also containing small quantities of copper, zinc, or bismuth. An alloy of 12 parts tin, 1 part antimony, and a small quantity of copper, forms a superior kind of *pewter*. Alloys of antimony with tin, or tin and lead, are now much used for machinery-bearings in place of gun-metal. Alloys of antimony with nickel and with silver occur as natural minerals.

Antimonious sulphide enters into the composition of the blue signal-lights used at sea.*

ARSENIC.

166. *Its Preparation, Properties, etc.* — Arsenic (which, like antimony, is often reckoned as a metal) is some-

* Blue or Bengal light : —

Dry potassic nitrate (saltpetre) . . . 6 parts.

Sulphur 2 "

Antimonious sulphide 1 part.

All in fine powder, and intimately mixed.

times found native. It occurs in considerable quantity as a constituent of many minerals, combined with metals, sulphur, and oxygen. In the oxidized state it has been found in very minute quantity in a great many mineral waters. The largest proportion is derived from the roasting of natural arsenides of iron, nickel, and cobalt. The operation is conducted in a reverberatory furnace, and the volatile products are condensed in a long and nearly horizontal chimney, or in a kind of tower of brickwork, divided into numerous chambers. The crude arsenious oxide thus produced is purified by sublimation, and then heated with charcoal in a retort; the arsenic is reduced, and readily sublimes.

Arsenic has a steel-gray color, and high metallic lustre; it is crystalline and very brittle; it tarnishes in the air, but may be preserved unchanged in pure water. Its density, in the solid state, is 5.7 to 5.9. When heated, it volatilizes without fusion, and if air be present, oxidizes to arsenious oxide. Its vapor density, compared with that of hydrogen, is 150, which is twice its atomic weight, so that its molecule in the gaseous state, like that of phosphorus, occupies only half the volume of a molecule of hydrogen. The vapor has the odor of garlic.

Arsenic combines with metals in the same manner as sulphur and phosphorus, which it resembles, especially the latter, in many respects.

Arsenic, like nitrogen, behaves in most respects as a triad element, not being capable of uniting with more than three atoms of any one monad element. Thus it forms the compounds AsCl_3 , AsBr_3 , etc., but no compound analogous to the pentachloride of phosphorus or antimony. But just as ammonia, H_3N , can take up the elements of muriatic acid to form sal-ammoniac, H_4NCl , in which nitrogen appears quinquivalent, so likewise can $\text{H}_3\text{As}'''$ unite with the chlorides, bromides, etc., of the radicals, methyl,

ethyl, etc., to form salts in which the arsenic appears to be quinquivalent.

Arsenic likewise forms two oxides; *arsenious oxide*, $\text{As}^{\text{III}}_2\text{O}_3$, and *arsenic oxide*, $\text{As}^{\text{V}}_2\text{O}_5$, with corresponding acids and salts, analogous to the phosphorous and phosphoric compounds; the arsenates, in particular, are isomorphous with the phosphates, and resemble them closely in many other respects.

167. *Compounds with Chlorine, Iodine, etc.* — *Arsenious Chloride*, AsCl_3 , is the only known chloride of arsenic. It is produced, with emission of heat and light, when powdered arsenic is thrown into chlorine gas. It is a colorless, volatile, highly poisonous liquid, decomposed by water into arsenious and muriatic acids. *Arsenious iodide*, AsI_3 , is formed by heating metallic arsenic with iodine; it is a deep-red crystalline substance, capable of sublimation. The corresponding *bromide* and *fluoride* are both liquid.

168. *Hydric Arsenide or Arsenetted Hydrogen.* — This compound, H_3As , analogous in composition to ammonia, is obtained pure by the action of strong muriatic acid on an alloy of equal parts of zinc and arsenic, and is produced in greater or less proportion whenever hydrogen is set free in contact with arsenious acid. It is a colorless gas, of specific gravity 2.695, slightly soluble in water, and having the smell of garlic. It burns, when kindled, with a blue flame, generating arsenious acid. It is also decomposed by transmission through a red-hot tube. Many metallic solutions are precipitated by this substance. When inhaled, it is exceedingly poisonous, even in very minute quantity.

169. *Arsenious Anhydride, Acid, and Salts.* — *Arsenious anhydride* (or *white arsenic*), As_2O_3 , is commonly met with in the form of a heavy, white, glassy-looking substance, which has evidently undergone fusion. When freshly prepared it is often transparent, but by keeping becomes

opaque, at the same time slightly diminishing in density, and acquiring a greater degree of solubility in water. 100 parts of that liquid dissolve at 100° about 11.5 parts of the opaque variety; the largest portion separates, however, on cooling, leaving about 3 parts dissolved. The solution, which contains *arsenious acid*, feebly reddens litmus. Cold water, agitated with powdered arsenious anhydride, takes up a still smaller quantity. Alkalies dissolve this substance freely, forming *arsenites*; compounds with ammonia, baryta, strontia, lime, magnesia, and manganous oxide also have been formed; the silver salt is a beautiful lemon-yellow precipitate. The anhydride or acid itself has a feeble sweetish and astringent taste, and is a most fearful poison.

170. *Arsenic Anhydride, Acid,* and Salts.* — When powdered arsenious anhydride is dissolved in hot muriatic acid, and oxidized by the addition of nitric acid, the latter being added as long as red vapors are produced, the whole then cautiously evaporated to complete dryness, and the residue heated to low redness, arsenic anhydride, As_2O_3 , remains in the form of a white mass, which has no action upon litmus. When strongly heated it is resolved into arsenious anhydride and free oxygen. In water it dissolves slowly but completely, giving a highly acid solution, which, on being evaporated to a sirupy consistence, deposits, after a time, crystals of arsenic acid. These crystals, when heated to 100°, give off their water of crystallization and leave *trihydrated arsenic acid*, H_3AsO_4 ; at 140° — 160° the *dihydrate*, $\text{H}_4\text{As}_2\text{O}_7$; and at 260° the *monohydrate*, HAsO_3 . The aqueous solutions of the three hydrates and of the anhydride exhibit exactly the same characters, and all contain the trihydrate, the other hydrates being immediately converted into that compound when dissolved in water; in this respect the hydrates of arsenic acid differ essentially from those of phosphoric acid.

Arsenic acid is a very powerful acid, forming salts isomorphous with the corresponding phosphates; it is also tribasic. A *sodic arsenate*, $\text{Na}_2\text{HAsO}_4 \cdot 12\text{H}_2\text{O}$, undistinguishable in appearance from common sodic phosphate, may be prepared by adding the carbonate to a solution of arsenic acid, until an alkaline reaction is apparent, and then evaporating.

171. *Sulphides*. — Two sulphides of arsenic are known. The *disulphide*, As_2S_3 , occurs native as *realgar*. It is formed artificially by heating arsenic acid with the proper proportion of sulphur. It is an orange-red, fusible, and volatile substance, used in painting, and by the pyrotechnist in making *white fire*. The *trisulphide* or *arsenious sulphide*, As_2S_5 , also occurs native as *orpiment*, and is prepared artificially by fusing arsenic with the appropriate quantity of sulphur, or by precipitating a solution of arsenious acid with hydric sulphide. It is a golden-yellow, crystalline substance, fusible, and volatile by heat.

The *disulphide* and *trisulphide* are sulphur-acids, uniting with other metallic sulphides to form sulphur-salts. Those of the disulphide are called *hyposulpharsenites*; they are but little known. The salts of arsenious sulphide are called *sulpharsenites*. Sulphur-salts, called *sulpharsenates*, corresponding in composition to the arsenates, are produced by passing gaseous hydric sulphide through solutions of arsenates.

172. *Marsh's Test for Arsenious Acid*. — There are various methods of detecting the presence of arsenious acid. One of the most delicate was devised by Marsh, and is known by his name. The suspected liquid is acidulated with sulphuric acid, and placed in contact with metallic zinc; the hydrogen reduces the arsenious acid and combines with the arsenic, if any be present. The gas is burned at a jet, and a piece of glass or porcelain held in the flame, when any admixture of hydric arsenide is at

once known by the production of a brilliant black spot of reduced arsenic on the porcelain; or the gas is passed through a glass tube heated at one or two places to redness, whereby the hydric arsenide is decomposed, a ring of reduced arsenic appearing behind the heated portion of the tube.

Hydric antimonide, however, gives a similar result. In order to distinguish the two substances, the gas may be passed into a solution of argentic nitrate. Both gases give rise to a black precipitate, which, in the case of hydric antimonide, consists of argentic antimonide, Ag_3Sb , whilst in the case of hydric arsenide, it is pure silver, the arsenic being then converted into arsenious acid, which combines with a portion of argentic oxide. The argentic arsenite remains dissolved in the nitric acid which is liberated by the precipitation of the silver, and may be thrown down with its characteristic yellow color by adding ammonia to the liquid filtered off from the black precipitate. The black argentic antimonide, when carefully washed, and subsequently boiled with a solution of tartaric acid, yields a solution containing antimony only, from which hydric sulphide separates the characteristic orange-yellow precipitate of antimonious sulphide.

173. *Reinsch's Test.* — A slip of copper-foil boiled in the poisoned liquid, previously acidulated with muriatic acid, withdraws the arsenic, and becomes covered with a white alloy. By heating the metal in a glass tube, the arsenic is expelled, and oxidized to arsenious acid. This is called *Reinsch's test*.

BISMUTH.

174. *Its Properties, etc.* — Bismuth is found chiefly uncombined, disseminated through various rocks, from which it is separated by simple exposure to heat. It is highly crystalline and very brittle: it has a reddish-white color, and a

density of 9.9. Crystals of great beauty may be obtained by slowly cooling a considerable mass of this substance until solidification has commenced, then piercing the crust, and pouring out the fluid residue. Bismuth melts at about 260° , and volatilizes at a high temperature. It is little oxidized by the air, but when strongly heated burns with a bluish flame. Nitric acid, somewhat diluted, dissolves it freely.

Bismuth forms three classes of compounds, in which it is bi-, tri-, and quinquivalent respectively. The tri-compounds are the most stable and the most numerous. The only known compounds in which bismuth is quinquivalent are indeed the pentoxide, Bi_2O_5 , together with the corresponding acid and metallic salts. Several bismuth compounds are known in which the metal is apparently bivalent, but really trivalent; two atoms combining thus, Bi-Bi , to form the tetrad radical $[\text{Bi}_2]_4$. Thus we have $[\text{Bi}_2]_4\text{Cl}_4$ and $[\text{Bi}_2]_4\text{O}_4$. These compounds are unimportant, except as illustrations of the tendency of atoms of the same kind to unite so as to form radicals.

175. *Oxides.* — The *trioxide*, or *bismuthous anhydride*, Bi_2O_3 , is a straw-yellow powder, obtained by gently igniting the neutral or basic nitrate. It is fusible at a high temperature.

The *hydrate*, $\text{HBi}^{\text{III}}\text{O}_3$, is obtained as a white precipitate when a solution of the nitrate is decomposed by an alkali. Both the hydrate and the anhydride dissolve in the stronger acids, forming the bismuthous salts, which have the composition $\text{Bi}^{\text{III}}\text{R}_3$, where R denotes an acid radical; e. g., $\text{Bi}^{\text{III}}\text{Cl}_3$, $\text{Bi}^{\text{III}}(\text{NO}_3)_3$, $\text{Bi}^{\text{III}}_2(\text{SO}_4)_3$. Many of these salts crystallize well, but cannot exist in solution unless an excess of acid is present. On diluting the solutions with water, a basic salt is precipitated, and an acid salt remains in solution.

The *normal nitrate*, $\text{Bi}^{\text{III}}(\text{NO}_3)_3$, forms large transparent

colorless crystals, which are decomposed by water in the manner just mentioned, yielding an acid solution containing a little bismuth, and a brilliant white crystalline powder, which varies to a certain extent in composition, according to the temperature and the quantity of water employed. A solution of the nitrate, free from any great excess of acid, poured into a large quantity of cold water, yields an insoluble basic nitrate, very similar in appearance to the above, but containing rather a large proportion of bismuthous anhydride. This basic nitrate was once much used as a cosmetic, but it is said to injure the skin, rendering it yellow and leather-like. It is used in medicine.

The *pentoxide*, or *bismuthic anhydride*, Bi_2O_5 , is a reddish powder, insoluble in water. It combines with bases, but the compounds are not very well known.

176. *The Nitrogen Group*.—The five elements, nitrogen, phosphorus, arsenic, antimony, and bismuth, form a third group of elements with well-marked family traits. In these we have the same gradation of properties as already noticed in the preceding group. Nitrogen is a gas; phosphorus is a solid of a specific gravity of about 2; arsenic has a specific gravity of 5.6; antimony of 6.7; and bismuth of 9.8. The atomic weight of $\text{N} = 14$, $\text{P} = 31$, $\text{As} = 75$, $\text{Sb} = 122$, and $\text{Bi} = 210$. The metallic character in Bi is quite marked; in Sb , somewhat less marked; in As , doubtful; and in P and N , wholly wanting.

The family traits of this group are well seen in the compounds of these elements with H and O . Thus, we have:—

H_3N	N_2O_3	N_2O_5
H_3P	P_2O_3	P_2O_5
H_3As	As_2O_3	As_2O_5
H_3Sb	Sb_2O_3	Sb_2O_5
	Bi_2O_3	Bi_2O_5

Ammonia is powerfully basic ; hydric phosphide, slightly so ; while hydric arsenide and antimonide are not basic in the least.

These compounds are decomposed by exposure to heat ; H_3N requiring a high temperature, H_3P a lower one, H_3As one lower still, and H_3Sb , the lowest of all. Bi has so slight an affinity for H that it does not appear to form any compound with it. N_2O_3 is a highly volatile liquid ; P_2O_3 , a very volatile solid ; As_2O_3 , a less volatile solid ; Sb_2O_3 , a solid volatile only at a full red heat ; and Bi_2O_3 , a solid that can be volatilized only at an extremely high temperature. N_2O_3 and P_2O_3 are strongly acid ; As_2O_3 is feebly acid ; Sb_2O_3 is sometimes acid and sometimes basic ; and Bi_2O_3 , decidedly basic. Again, in N_2O_5 , the acid character is intense ; in P_2O_5 , strong but less intense than in the former ; in As_2O_5 , still less intense ; in Sb_2O_5 , indistinct ; and in Bi_2O_5 , wholly wanting.

In general terms, the chemical energy of these five elements diminishes with the increase of their atomic weights.

As the *quasi* non-metal, hydrogen, connects the more powerful metals, potassium and sodium, with the more powerful non-metals, chlorine and bromine, so the *quasi* metals of this group serve to connect the weaker metals with the weaker non-metals.

The perissad metals and non-metals may be regarded as the halves of a ring, joined by hydrogen on one side and by bismuth on the other.

BORON.

177. *Its Preparation and Properties.*—This element, the basis of *boric* or *boracic acid*, is prepared by heating the double fluoride of boron and potassium with metallic potassium in a small iron vessel, and washing out the soluble

salts with water. It is a dull, greenish-brown powder, which burns in the air when heated, producing boric oxide. Nitric acid, alkalis in the fused state, chlorine, and other agents, attack it readily.

Wöhler and Deville have obtained a modification of boron which crystallizes in square octohedrons, generally of a brownish color, possessing very nearly the hardness and refractive power of diamond. It is infusible in the flame of the oxy-hydrogen blowpipe, but burns in oxygen at the same temperature at which the diamond is oxidized. Its specific gravity is 2.68, and it is known as *diamond boron*.

By fusing boric oxide with aluminium, Wöhler and Deville likewise obtained, together with diamond boron, a small quantity of a graphite-like substance which they at first regarded as a graphitoidal modification of boron; but, by more recent experiments, they have found that it is a compound of boron with aluminium. This compound is obtained in larger quantity by passing the vapor of boric chloride over fused aluminium. It crystallizes in thin opaque six-sided plates, having a pale copper-color, and perfect metallic lustre.

178. *Boric Oxide and Acid*. — There is but one oxide of boron, B_2O_3 , *boric oxide*, containing 11 parts of boron and 48 of oxygen. It unites with water and metallic oxides, forming boric acid and metallic borates.

Hydric borate (boric or boracic acid), H_3BO_3 , is found in solution in the water of the hot volcanic lagoons of Tuscany, whence a large supply is at present derived. It is also easily made by decomposing with sulphuric acid a hot solution of *borax*, a salt brought from the East Indies, consisting of sodic borate.

Boric acid crystallizes in transparent colorless plates, soluble in about 25 parts of cold water, and in a much smaller quantity at the boiling heat; the acid has but little

taste, and feebly affects vegetable colors. When heated, it loses water, and melts to a glassy transparent mass of anhydrous boric oxide, which dissolves many metallic oxides with great ease. The crystals dissolve in alcohol, and the solution burns with a green flame.

179. *Boric Fluoride*. — By heating in a glass flask or retort 1 part of vitrified boric oxide, 2 of fluor-spar, and 12 of oil of vitriol, a gaseous *boric fluoride*, BF_3 , may be obtained, and collected over mercury. It is a transparent gas, very soluble in water, and very heavy; it forms dense fumes in the air.

180. *Boric Chloride*. — This compound, BCl_3 , was formerly believed to be a permanent gas; recent researches have proved that it is a liquid, boiling at 17° , decomposed by water, with production of boric and muriatic acids, and fuming strongly in the air. It may be most easily obtained by exposing to the action of dry chlorine at a very high temperature an intimate mixture of glassy boric oxide and charcoal.

There is also a *Boric bromide*, HBr_3 .

CARBON OR QUADRIVALENT GROUP OF NON-METALS.

CARBON.

181. *Its Forms, Properties, etc.* — Carbon occurs in a state of purity, and crystallized, in two distinct and very dissimilar forms; namely, as *diamond*, and as *graphite*, or *plumbago*. It constitutes a large proportion of all organic structures, animal and vegetable; when these latter are exposed to destructive distillation in close vessels, a great part of their carbon remains, obstinately retaining some of the hydrogen and oxygen, and associated with the earthy and alkaline matter of the tissue, giving rise to the many

varieties of *charcoal*, *coke*, etc. This residue, when perfectly separated from all foreign matter, constitutes a third variety of carbon.

182. *The Diamond*. — The diamond is one of the most remarkable substances known. Long prized on account of its brilliancy as an ornamental gem, the discovery of its curious chemical nature confers upon it a high degree of scientific interest. Several localities in India, the island of Borneo, and more especially Brazil, furnish this beautiful substance. It is always distinctly crystallized, often quite transparent and colorless, but now and then having a shade of yellow, pink, or blue. The origin and true geological position of the diamond are unknown; it is always found embedded in gravel and transported materials whose history cannot be traced. The crystalline form of the diamond is that of the regular octohedron or cube, or some figure geometrically connected with these. Many of the octohedral crystals exhibit a very peculiar appearance, arising from the faces being curved or rounded, which gives to the crystal an almost spherical figure.

The diamond is infusible and unalterable even by a very intense heat, if air be excluded; but when heated, thus protected, between the poles of a strong galvanic battery, it is converted into coke or graphite. Heated to whiteness in a vessel of oxygen, it readily burns, yielding carbonic acid gas.

The diamond is the hardest substance known; it admits of being split or cloven without difficulty in certain particular directions, but can only be cut or abraded by the same material. The powder rubbed off in this process serves for polishing the new faces, and is also highly useful to the lapidary and seal-engraver. One very curious and useful application of the diamond is made by the glazier. A *fragment* of this mineral, like a bit of flint, or any other hard substance, scratches the surface of the glass; a *crystal*

of diamond, having the rounded octohedral figure spoken of, held in one particular position on the glass, — namely, with an edge formed by the meeting of two adjacent faces presented to the surface, — and then drawn along with gentle pressure, causes a split or cut, which penetrates to a considerable depth into the glass, and determines its fracture with perfect certainty.

183. *Graphite*. — Graphite or plumbago appears to consist essentially of pure carbon, although most specimens contain iron, the quantity of which varies from a mere trace up to five per cent. Graphite is a somewhat rare mineral; the finest and most valuable for pencils is brought from Borrowdale, in Cumberland (England), where a kind of irregular vein traverses the ancient slate-beds of that district.* Crystals are not common; when they occur, they have the figure of a short six-sided prism, — a form bearing no geometric relation to that of the diamond.

Graphite is often formed artificially in certain metallurgic operations; the brilliant scales which sometimes separate from melted cast-iron on cooling, called by the workmen *kish*, consist of graphite.

* The graphite which can be directly cut for pencils occurring only in limited quantity, powdered graphite, obtained from the inferior varieties of the mineral, is now frequently consolidated for this purpose. The mechanical division of graphite presents considerable difficulties, which may be entirely obviated by adopting a chemical process suggested by Sir Benjamin Brodie, applicable, however, only to certain varieties, such as Ceylon graphite. This process consists in introducing the coarsely powdered graphite, previously mixed with $\frac{1}{4}$ of its weight of potassic chlorate, into 2 parts of concentrated sulphuric acid, which is heated in a water-bath until the evolution of acid fumes ceases. The acid is then removed by water, and the graphite dried. Thus prepared, this substance, when heated to a temperature approaching a red heat, swells up to a bulky mass of finely divided graphite. The graphite lately discovered in Siberia, which attracted such general attention at the Great Exhibition of 1862, likewise admits of being purified by Sir B. Brodie's process.

184. *Lamp-Black and other Forms of Charcoal.* — Lamp-black, the soot produced by the imperfect combustion of oil or resin, is the best example that can be given of carbon in its uncrystallized or *amorphous* state. To the same class belong the different kinds of *charcoal*. Charcoal from bones and animal matters in general is a very valuable substance, on account of the extraordinary power it has (28) of removing coloring matters from organic solutions. It is used for this purpose by the sugar-refiners to a very great extent, and also by the manufacturing and scientific chemist. The property in question is possessed by all kinds of charcoal in a small degree.

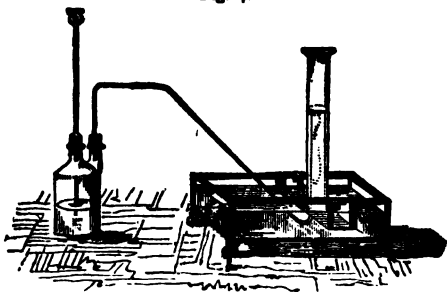
Charcoal made from box, or other dense wood, has the property of condensing gases and vapors into its pores: of ammonia (38) it is said to absorb not less than ninety times its volume, while of hydrogen it takes up less than twice its own bulk, the quantity being apparently connected with the property in the gas of becoming liquid. The absorbing power is considerably increased by saturating charcoal with solution of platinum, and subsequently igniting it, so as to coat the charcoal with a thin film of platinum. Dr. Stenhouse, who suggested this plan, finds that the gases thus absorbed undergo a kind of oxidation within the pores of the charcoal.

185. *Compounds of Carbon and Oxygen.* — There are two direct inorganic compounds of carbon and oxygen: *carbonic oxide*, CO , and *carbonic anhydride*, CO_2 .

186. *Carbonic Anhydride (Carbonic Acid).* — This compound is always produced when charcoal burns in air or in oxygen gas: it is most conveniently obtained, however, for study, by decomposing a carbonate with one of the stronger acids. For this purpose, the apparatus shown in Figure 48 may be employed: fragments of marble are put into the bottle with enough water to cover the extremity of the funnel-tube, and muriatic acid is added by the latter,

until the gas is freely disengaged. Chalk-powder and dilute sulphuric acid may be used instead. The gas may be

Fig. 48.



collected over water, although with some loss ; or very conveniently by displacement, if it be required dry.

Carbonic anhydride is a colorless gas ; it has an agreeable pungent taste and odor, but cannot be respired. Its specific gravity is 1.524, so that it can be poured from one vessel to another, like a liquid.

A lighted taper plunged into carbonic anhydride is instantly extinguished. When diluted with three times its volume of air, it still retains the power of putting out a light. The gas is easily distinguished from nitrogen, which is also incapable of supporting combustion, by its turning lime-water milky white.

Cold water dissolves about its own volume of carbonic anhydride, whatever be the density of the gas with which it is in contact ; and the solution temporarily reddens litmus-paper. In common soda-water, and also in effervescent wines, we have examples of the solubility of the gas. Even boiling water absorbs a perceptible quantity.

The gas can be liquefied by a pressure of between 27 and 28 atmospheres at 0° , according to Mr. Adams. The liquid is colorless and limpid, lighter than water, and four times more expansible than air ; it mixes in all proportions

with ether, alcohol, naphtha, oil of turpentine, and carbonic disulphide, and is insoluble in water and fat oils. In this condition it does not exhibit any of the properties of an acid.

The *carbonates* form a very large and important group of salts, some of which occur in nature in great quantities, as the carbonates of calcium and magnesium. They contain the elements of carbonic anhydride and a metallic oxide. Calcic carbonate, CaCO_3 , for example, is composed of 44 parts by weight of carbonic anhydride and 56 parts of calcic oxide or lime, or of 12 carbon, 48 oxygen, and 40 calcium. But they are never formed by the direct union of dry carbonic anhydride with a dry metallic oxide, the intervention of water being always required to bring about the combination. Potassic carbonate (pearlash) is the chief constituent of wood-ashes; sodic carbonate is contained in the ashes of marine plants. These carbonates are soluble in water. The other metallic carbonates, which are insoluble, may be formed by *double decomposition* (92) on mixing a solution of potassic or sodic carbonate with a soluble metallic salt.

The solution of carbonic anhydride in water may be supposed to contain *hydric carbonate* or *carbonic acid*, H_2CO_3 ; but this compound is not known in a separate state.

187. *Carbonic Oxide*.—When carbonic anhydride is passed over red-hot charcoal or metallic iron, one half of its oxygen is removed, and it becomes converted into *carbonic oxide*, CO . A very good method of preparing this gas is to put into a flask fitted with a bent tube some crystallized oxalic acid, and pour upon it five or six times as much strong oil of vitriol. On heating the mixture, the oxalic acid is resolved into water, carbonic anhydride, and carbonic oxide. $\text{C}_2\text{H}_2\text{O}_4$ (oxalic acid) $= \text{CO} + \text{CO}_2 + \text{H}_2\text{O}$. By passing the gases through a strong solution of caustic

potash, the CO_2 is withdrawn by absorption, while the CO remains unchanged. Another method is to heat finely powdered *yellow prussiate of potash* (potassic ferrocyanide) with eight or ten times its weight of concentrated sulphuric acid. The salt is entirely decomposed, yielding a most copious supply of perfectly pure carbonic oxide, which may be collected over water in the usual manner. $\text{K}_4\text{C}_6\text{N}_6\text{Fe}$ (potassic ferrocyanide) $+ 6\text{H}_2\text{O} + 6\text{H}_2\text{SO}_4 = 6\text{CO} + 2\text{K}_2\text{SO}_4$ (potassic sulphate) $+ 3(\text{NH}_4)_2\text{SO}_4$ (ammonic sulphate) $+ \text{FeSO}_4$ (ferrous sulphate).

CO is a combustible gas; it burns with a beautiful pale-blue flame, generating CO_2 . It has never been liquefied. It is colorless, has very little odor, and is extremely poisonous. Its specific gravity is 0.973.

CO unites with chlorine under the influence of light, forming a pungent, suffocating compound, possessing acid properties, called *phosgene gas*, or *carbonylic chloride*. It is made by mixing equal volumes of CO and chlorine, both perfectly dry, and exposing the mixture to sunshine. The gases unite quietly, the color disappears, and the volume becomes reduced to one half.

188. *Compounds of Carbon and Hydrogen.* — The compounds of carbon and hydrogen already known are almost innumerable. They properly belong to the domain of organic chemistry; but it will be found convenient to describe two of them in this part of the book.

189. *Marsh Gas (Methylic Hydride, Light Carburetted Hydrogen).* — This gas is often abundantly disengaged in coal-mines from the fresh-cut surface of the coal, and from remarkable apertures or *blowers*, which emit for a great length of time a copious stream or jet of gas, probably existing in a state of compression, pent up in the coal.

If we stir the mud at the bottom of pools in which water-plants grow, it suffers bubbles of gas to escape, which may be easily collected. This is found to be chiefly

a mixture of marsh gas and carbonic anhydride ; the latter is easily absorbed by lime-water or caustic potash.

For a long time no method was known by which marsh gas could be produced by artificial means ; but Dumas has discovered a process by which it can be obtained perfectly pure, and in any quantity.

A mixture is made of 40 parts crystallized sodic acetate, 40 parts solid sodic hydrate, and 60 parts quicklime in powder. This mixture is put in a flask or retort, and strongly heated ; the gas is disengaged abundantly, and may be collected over water, while sodic carbonate remains behind. $\text{NaC}_2\text{H}_3\text{O}_2$ (sodic acetate) + NaHO (sodic hydrate) = CH_4 (marsh gas) + Na_2CO_3 (sodic carbonate).

Marsh gas is colorless and nearly inodorous, and does not affect vegetable colors. It burns with a yellow flame generating CO_2 and water. It is not poisonous, and may be respired to a great extent without apparent injury. Its density is about 0.559. It contains carbon and hydrogen associated in the proportion of 12 parts by weight of the former to 4 of the latter ; so that its symbol is CH_4 .

When chlorine is mixed with marsh gas over water no change follows, if light be excluded. Light, however, brings about decomposition ; muriatic acid, carbonic anhydride, and sometimes other products, being formed. It is important to remember that this gas is not acted upon by chlorine in the dark.

190. *Olefiant Gas (Ethylene).* — Strong alcohol is mixed with five or six times its weight of oil of vitriol in a glass flask, the tube of which passes into a wash-bottle containing caustic potash. A second wash-bottle, partly filled with oil of vitriol, is connected with the first, and furnished with a tube dipping into the water of the pneumatic trough. On the first application of heat to the contents of the flask, alcohol, and afterwards ether, make their appearance ; but, as the temperature rises, and the mixture blackens, the

ether-vapor diminishes in quantity, and its place becomes in great part supplied by a permanent inflammable gas ; CO_2 and SO_2 are also generated at the same time, besides traces of other products. The CO_2 and SO_2 are absorbed by the alkali in the first bottle, and the ether-vapor by the acid in the second, so that the olefiant gas is delivered tolerably pure. The entire reaction is too complex to be described at this point ; but the ethylene may be viewed as resulting from a simple *dehydration* of the alcohol by the oil of vitriol. $\text{C}_2\text{H}_5\text{O}$ (alcohol) = C_2H_4 (ethylene) + H_2O . Olefiant gas thus produced is colorless, neutral, and but slightly soluble in water. Alcohol, ether, oil of turpentine, and even olive oil, as Faraday has observed, dissolve it to a considerable extent. It has a faint odor of garlic. On the approach of a lighted taper, it takes fire, and burns with a splendid white light, far surpassing in brilliancy that produced by marsh gas. This gas, when mixed with oxygen and fired, explodes with extreme violence. Its density is 0.981.

Ethylene is decomposed by passing it through a tube heated to bright redness ; a deposit of charcoal and tar takes place, and the gas becomes converted into marsh gas, or even into free hydrogen, if the temperature be very high.

Chlorine acts upon ethylene in a remarkable manner. When the two bodies are mixed, even in the dark, they combine

Fig. 49.



in equal measures, and give rise to a heavy oily liquid, $C_2H_4Cl_2$, of sweetish taste and ethereal odor, to which the name of *ethylic chloride* or *Dutch liquid* is given. It is from this peculiarity that the term *olefiant* gas is derived.

A pleasing and instructive experiment may also be made by mixing in a tall jar two measures of chlorine and one of ethylene, and then quickly applying a light to the mouth of the vessel. The chlorine and hydrogen unite with flame, which passes quickly down the jar, while the whole of the carbon is set free in the form of a thick black smoke (Figure 49).

SILICON.

191. *Its Preparation, Properties, etc.* — Silicon, sometimes called *silicium*, is a very abundant element, and one of great importance. In combination with oxygen as *silica*, it forms a large component of the rocks and mineral masses of the earth.

Silicon is most readily obtained by heating the double fluoride of silicon and potassium in a glass tube, with metallic potassium. Violent action ensues, and silicon is set free in the form of a dark-brown powder, destitute of lustre. It burns when heated in the air; and is acted upon by sulphur and chlorine.

According to recent researches by Wöhler and Deville, silicon, like carbon, is capable of existing in three different modifications.

192. *Silica or Silicic Oxide.* — Silica, SiO_2 , is the only known oxide. Colorless transparent rock-crystal consists of silica very nearly in a state of purity; common quartz, agate, chalcedony, flint, and several other minerals, are also chiefly composed of it.

The following experiment furnishes silica in a state of complete purity, and at the same time exhibits one of the

most remarkable properties of silicon, — its attraction for fluorine. A mixture is made of equal parts fluor-spar and glass, both finely powdered, and put into a glass flask, with a quantity of oil of vitriol. A tolerably wide bent tube, fitted to the flask by a cork, passes to the bottom of a glass jar, into which enough mercury is poured to cover the extremity of the tube. The jar is then half filled with water, and heat is applied to the flask.

The first effect is the disengagement of hydric fluoride, which, finding itself in contact with the silica of the powdered glass, undergoes decomposition, water and silicic fluoride being produced. $4\text{HF} + \text{SiO}_2 = 2\text{H}_2\text{O} + \text{SiF}_4$ (silicic fluoride). The latter is a permanent gas, which escapes from the flask by the bent tube. By contact with a large quantity of water, it is in turn decomposed, yielding silica, which separates in a beautiful gelatinous condition, and an acid liquid, which is a double silicic and hydric fluoride, commonly called *hydrofluosilicic acid*. $3\text{SiF}_4 + 2\text{H}_2\text{O} = \text{SiO}_2 + 2\text{H}_2\text{SiF}_6$ (hydrofluosilicic acid).

The silica may be collected on a cloth filter, well washed, dried, and heated to redness to expel water.

Silicic fluoride, instead of being condensed into water, may be collected over mercury; it is a permanent gas, destitute of color, and very heavy. Admitted into the air, it condenses the moisture of the latter, giving rise to a thick white cloud.

Silica is a very fine, white, tasteless powder, having a density of about 2.66, fusible only by the oxy-hydrogen blowpipe. When once dried, silica is not sensibly soluble in water or dilute acids (with the exception of hydric fluoride). But on adding muriatic acid to a very dilute solution of potassic silicate, the liberated silica remains in solution. From this mixed solution of silica and potassic chloride, the latter may be separated by diffusion (41), whereby a moderately concentrated solution of silica in

water is obtained. This solution has a distinctly acid reaction.

Silica is essentially an acid oxide, forming salts with basic metallic oxides, and decomposing all salts of volatile acids when heated with them. In strong alkaline liquids it is freely soluble. When heated with bases, especially those which are capable of undergoing fusion, it unites with them and forms salts, which are sometimes soluble in water, as in the case of the potassic and sodic silicates, when the proportion of base is considerable. Common glass is a mixture of several silicates, in which the reverse of this happens, the silica being in excess. Even glass, however, is slowly acted upon by water.

193. *Silicic Hydride or Silicated Hydrogen.* — This gas was discovered by Buff and Wöhler, who obtained it by passing an electric current through a solution of common salt, the positive pole consisting of aluminium containing silicon. It is a colorless gas. It does not ignite spontaneously under ordinary atmospheric pressure; but if a bubble of air be passed into the rarefied gas standing over mercury, it takes fire and yields a deposit of amorphous silicon mixed with silica.

194. *Compound of Silicon and Chlorine.* — Silicon unites directly with chlorine, forming a tetrachloride, SiCl_4 . This is a colorless and very volatile liquid, boiling at 50° , of pungent, suffocating odor. In contact with water it yields gelatinous silica and muriatic acid.

195. *The Carbon Group.* — Carbon and silicon form a fourth family of elements, resembling each other closely in their allotropic states, and in the composition of their hydrides (CH_4 and SiH_4) and their oxides (CO_2 and SiO_2).

SUMMARY OF THE NON-METALS.*

Hydrogen. — Properly a metal, though it has many of the characteristics of a non-metal. Lightest substance known. Very widely diffused in nature. Seldom found in a free state. The essential constituent of all acids and bases, from which it is readily displaced. Very combustible. Best prepared by the action of zinc on dilute sulphuric acid. Its most important compound is water.

Fluorine. — A chief constituent of fluor-spar, CaF_2 , and of cryolite, $\text{Na}_3\text{Al}_2\text{F}_{12}$. Found also in a few other minerals and in the bones of animals, especially in the teeth. Undoubtedly a gas, but has not with certainty been isolated. Hydric fluoride is remarkable for its power of dissolving silica, with which it forms volatile products.

Chlorine. — Very widely distributed in nature, chiefly in combination with Na. Yellowish-green gas, soluble in water, liquefiable under pressure, but has never been frozen. Highly corrosive, and enters into direct union with most of the elements. Has a strong affinity for the metals. Destroys vegetable colors and noxious effluvia. Best prepared by gently heating a mixture of hydric chloride and manganic dioxide. Its most important compounds are common salt and muriatic acid. All its oxygen compounds are unstable and most of them explosive. Potassic chlorate is much used in making oxygen gas, and also in fireworks, and in the preparation of detonating powder. The compounds of Cl and N are peculiarly explosive.

* This Summary is to some extent independent of what precedes, and contains some additional facts. The aim has been to state concisely the leading points, both theoretical and practical, concerning each non-metal. If the teacher does not wish to go through with the entire chapter, he can make this Summary the basis of the study of the non-metals, referring back for the details on the more important subjects.

Bromine. — Associated with Cl in minute quantities, in saline waters, and in certain silver ores. A very volatile, deep red liquid. Its salts are used in photography and medicine.

Iodine. — Associated with Cl in still smaller quantities than Br. Obtained from the ashes of certain sea-weeds. A crystalline solid. Boils at 175° , forming a dense violet vapor. Gives starch paste a deep blue color. Slightly soluble in water, but readily soluble in alcohol, ether, and carbonic disulphide. Its salts are used in photography and medicine.

The three elements, Cl, Br, and I, form a natural group. They themselves and their compounds have that well-defined gradation of properties which marks a chemical series. They are all highly electro-negative elements, but this character becomes less distinct as we descend the series, and hence their chemical energy, as manifested by the strength of their affinity for hydrogen and the other electro-positive metals, diminishes as their atomic weights increase. This law, with few exceptions, holds for all the chemical groups.

Oxygen. — The most abundant and widely diffused of the elements. Exists in a free state in the atmosphere, but mixed with N. Has a very wide range of affinities. Exists in a passive, a partially active, and a wholly active state. The supporter of animal life and of combustion. Best prepared on a small scale by heating potassic chlorate.

Sulphur. — Widely and abundantly distributed in nature, chiefly in combination in various metallic sulphides and sulphates. The most abundant of these are iron pyrites, FeS_2 , and gypsum, CaSO_4 . Found native in volcanic districts. Obtained mainly from Sicily. Has well-marked allotropic states. Has a strong affinity for the metals, many of which burn in its vapor with great brilliancy. Has also a strong affinity for O, and is very combustible.

Used chiefly for making sulphuric acid, and vulcanizing india-rubber, but has also many subordinate uses in the arts and in medicine. Closely allied to O. Forms with H a compound analogous to water in structure, which is a valuable chemical reagent.

Selenium and Tellurium.—Two very rare elements closely allied to O and S, with which they form a well-marked natural group.

Nitrogen.—Chief constituent of the air, and the characteristic ingredient of animal tissue. Scarcely found, except in the air and in organized beings. Is very inert. Combines directly with no element except B and Ti. Has, nevertheless, great capacity for combination, and is distinguished for the large number and varied nature of its compounds. Nitric acid is one of the most corrosive agents known. Substitution products are formed by its action on certain organic compounds, one or more atoms of H being replaced by the radical NO_2 . Many of these compounds are terribly explosive. With H it forms ammonia gas, H_3N , in which it is trivalent. A single atom of this element, unassisted, does not appear to be able to hold together more than three atoms of H or of other univalent positive radicals. When brought in contact with acids, the N atoms suddenly manifest two additional affinities.

Phosphorus.—Found in nature, chiefly in combination with Ca. Very widely but sparingly distributed. An essential but subordinate constituent of many plants, and of all the higher animals. The most combustible of the elements. Has well-marked allotropic states. Chiefly used in the manufacture of matches. Obtained from bones. Forms several remarkable acids.

Arsenic.—One of the less abundant elements, but quite widely distributed. Has many of the properties of a metal, but is closely allied to P in its chemical relations. One of its compounds with O is the well-known poison.

Antimony. — Less abundantly distributed than As, to which it is closely allied. A constituent of type-metal and britannia-metal.

Bismuth. — One of the rarer elements, closely allied to As and P. N, P, As, Sb, and Bi form a natural group with marked gradation of properties.

Boron. — A very sparingly distributed element. Always found combined with O. In boric acid and in various borates it is electro-negative, while in tourmaline and in many artificial salts it acts the part of a basic radical. Its most important compound is borax, made in large quantities from the boric acid of the Tuscan lagoons.

Carbon. — “One of the most widely diffused, and one of the most important elements in the scheme of terrestrial nature. United to the three aeriform elements, O, H, and N, it forms the chief solid substratum of all organized structures. Combined with O, it forms the carbonic anhydride of the atmosphere, which is the food of the whole vegetable world. In a nearly pure condition, or combined with H, it is found in the strata, forming those deposits of coal and petroleum which are such great store-houses of light, heat, and motive power. Lastly, it is an essential constituent of the limestones and dolomites which form an important part of the rocky crust of the globe. The elementary substance is found in nature in three very different conditions, namely, coal, graphite, and diamond.” The atoms have a remarkable power of combining with one another by a part of their affinities, and of thus forming, as it were, the backbone of innumerable compounds.

Silicon. — Next to O the most abundant element. Constitutes about one fourth of the rocky crust of the globe. Always found in nature united with O, either as quartz or in the various silicates. Has, like C, three allotropic states.

THE METALS.

ALKALI GROUP OF METALS.

POTASSIUM.

196. *Its Discovery and Preparation.* — Potassium was discovered in 1807 by Sir H. Davy, who obtained it in very small quantity by exposing a piece of moistened potassic hydrate to the action of a powerful voltaic battery, the alkali being placed between a pair of platinum plates connected with the apparatus. Processes have since been devised for obtaining this metal in almost any quantity that can be desired.

An intimate mixture of potassic carbonate and charcoal is prepared by calcining, in a covered iron pot, the crude tartar of commerce ; when cold, it is mixed with one tenth part of charcoal in small lumps, and quickly transferred to a retort of stout hammered iron. The retort is introduced into a furnace and strongly heated. A wrought-iron tube, four inches long, serves to convey the vapors of potassium into a receiver, formed of two pieces of wrought iron, which are fitted closely to each other so as to form a shallow box only a quarter of an inch deep, and are kept together by clamp-screws. The object of giving the receiver this flattened form is to insure the rapid cooling of the potassium, and thus to withdraw it from the action of the carbonic oxide, which is disengaged during the entire process, and has a strong tendency to unite with the potassium, forming a dangerously explosive compound. The receiver

is kept cool by the application of a wet cloth to the outside. When the operation is complete, the receiver with the potassium is removed, and immediately plunged into a vessel of rectified Persian naphtha, provided with a cover and kept cool by immersion in water. When the apparatus is sufficiently cooled, the potassium is detached and preserved under naphtha.

If the potassium be wanted absolutely pure, it must be afterwards redistilled in an iron retort, into which some naphtha has been put, that its vapor may expel the air and prevent oxidation of the metal.

197. *Its Properties.*—Potassium is a brilliant white metal, with a high degree of lustre; at the common temperature of the air it is soft, and may be easily cut with a knife, but at 0° it is brittle and crystalline. It melts completely at 62.5° , and distils at a low red heat. It floats on water, its specific gravity being only 0.865.

Exposed to the air, potassium oxidizes instantly, a tarnish covering the surface of the metal, which quickly thickens to a crust of caustic potash. Thrown upon water (50), it takes fire spontaneously, and burns with a beautiful purple flame, yielding an alkaline solution. When it is brought into contact with a little water in a jar standing over mercury, the liquid is decomposed with great energy, and hydrogen liberated. Potassium is always preserved under the surface of naphtha.

198. *Potassic Chloride.*—This salt, KCl , is obtained in large quantity in the manufacture of the chlorate; it is easily purified from any portions of the latter by exposure to a dull red heat. Within the last few years large quantities of this salt have been obtained from sea-water, by a peculiar process suggested by M. Balard.* It is also contained in kelp, and is separated for the use of the alum-

* Reports by the Juries of the International Exhibition of 1862, Class II.

maker. Considerable quantities of it are now obtained from the salt-beds of Stassfurt, near Magdeburg, in Prussia.

Potassic chloride closely resembles common salt in appearance, and, like that substance, crystallizes in cubes. The crystals dissolve in three parts of cold, and in a much smaller quantity of boiling water. They are anhydrous, have a simple saline taste, with slight bitterness, and fuse when exposed to a red heat.

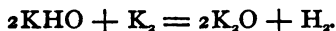
199. *Potassic Iodide*. — KI is an important medicinal compound. It crystallizes in cubes, which are often, from some unexplained cause, milk-white and opaque; they are anhydrous, and fuse readily when heated. The salt is very soluble in water, but not deliquescent, when pure, in a moderately dry atmosphere; it is dissolved by alcohol.

Solution of potassic iodide (like those of all the soluble iodides) dissolves a large quantity of free iodine, forming a deep-brown liquid, not decomposed by water.

200. *Potassic Bromide*. — This compound, KBr, is a colorless and very soluble salt, quite undistinguishable in appearance and in many of its properties from the iodide. It has come to be extensively used in medicine.

201. *Potassic Oxides*. — Potassium combines with oxygen in three proportions, forming a monoxide, K_2O , a dioxide, K_2O_2 , and a tetroxide, K_2O_4 , besides a hydrate, KHO , corresponding to the monoxide.

Potassic monoxide, K_2O , also called *anhydrous potash* or *potassa*, is formed when potassium in thin slices is exposed at ordinary temperatures to dry air free from carbonic anhydride; also when the hydrate is heated with an equivalent quantity of metallic potassium: —



It is a white solid, very deliquescent and caustic, combines energetically with water, forming potassic hydrate, and

becoming incandescent when moistened with it ; melts at a red heat, and volatilizes at very high temperatures.

202. *Potassic Hydrate*. — This compound, commonly called *caustic potash*, or *potassa*, is a very important substance, and one of great practical utility. It is always prepared for use by decomposing the carbonate with calcic hydrate (slaked lime). K_2CO_3 (potassic carbonate) + CaH_2O_2 (calcic hydrate) = $2KHO$ + $CaCO_3$ (calcic carbonate).

Pure potassic hydrate is also easily obtained by heating to redness for half an hour, in a covered copper vessel, one part of pure powdered nitre with two or three parts of finely divided copper foil. The mass, when cold, is treated with water.

Potassic hydrate is a white solid substance, very deliquescent and soluble in water. Alcohol also dissolves it freely, which is the case with comparatively few potassium compounds ; the solid hydrate of commerce, which is very impure, may thus be purified. The solution of this substance possesses, in the very highest degree, the properties termed *alkaline* : it restores the blue color to litmus which has been reddened by an acid ; neutralizes completely the most powerful acids ; has a nauseous and peculiar taste ; and dissolves the skin, and many other organic matters. It is frequently used by surgeons as a cautery, being moulded into little sticks for that purpose.

Potassic hydrate, both in the solid state and in solution, rapidly absorbs carbonic acid from the air ; hence it must be kept in closely stopped bottles. It is not decomposed by heat, but volatilizes undecomposed at a very high temperature. When imperfectly prepared, or partially altered by exposure, it effervesces with an acid.

203. *Potassic Nitrate* (*Nitre or Saltpetre*). — This important compound, KNO_3 , is a natural product, being disengaged by a kind of efflorescence from the surface of the

soil in certain dry and hot countries. It may also be produced by the oxidation of ammonia in presence of a powerful base.

In France, large quantities of artificial nitre are prepared by mixing animal refuse of all kinds with old mortar or calcic hydrate and earth, and placing the mixture in heaps, protected from the rain by a roof, but freely exposed to the air. From time to time the mass is turned over, to expose fresh surfaces to the air. When much salt has been formed the mixture is lixiviated(206), and the solution, which contains calcic nitrate, is mixed with potassic carbonate; calcic carbonate is formed, and the nitric acid transferred to the alkali. The filtered solution is then made to crystallize, and the crystals are purified by re-solution and crystallization.

Considerable quantities of nitre are now manufactured by decomposing native sodic nitrate (Chili saltpetre) with potassic carbonate or chloride. In Belgium the potassic carbonate from the ashes of the beet-root sugar manufactories is largely used for this purpose; the nitre thus made is very pure, and is produced at a low price.

Saltpetre crystallizes in anhydrous six-sided prisms, with dihedral summits, belonging to the rhombic or trimetric system; it is soluble in 7 parts of water at 15.5° , and in its own weight of boiling water. Its taste is saline and cooling, and it is without action on vegetable colors. At a temperature below redness it melts, and by a strong heat is completely decomposed.

When it is thrown on the surface of many metals in a state of fusion, or when mixed with combustible matter and heated, rapid oxidation ensues, at the expense of the oxygen of the nitric acid. Examples of such mixtures are found in common gunpowder, and in nearly all pyrotechnic compositions, which burn in this manner independently of the oxygen of the air, and even under water.

204. *Gunpowder.* — Gunpowder is made by very intimately mixing together potassic nitrate, charcoal, and sulphur, in proportions which approach 2 molecules of nitre, 3 atoms of carbon, and 1 atom of sulphur.

These quantities give, expressed in decimals, and compared with the proportions used in the manufacture of the English government powder, the following results :—

	Proportions in theory.	Proportions in practice.
Potassic nitrate . . . . .	.748	.75
Charcoal . . . . .	.133	.15
Sulphur . . . . .	.119	.10
	<hr/>	<hr/>
	1.000	1.00

The nitre is rendered very pure by the means already mentioned, freed from water by fusion, and ground to fine powder ; the sulphur and charcoal, the latter being made from light wood, as dogwood or alder, are also finely ground, after which the materials are weighed out, moistened with water, and thoroughly mixed by grinding under an edge-mill. The mass is then subjected to great pressure, and the mill-cake thus produced broken in pieces, and placed in sieves made of perforated vellum, moved by machinery, each containing, in addition, a round piece of heavy wood. The grains of powder broken off by attrition fall through the holes in the skin, and are easily separated from the dust by sifting. The powder is, lastly, dried by exposure to steam-heat, and sometimes glazed or polished by agitation in a kind of cask mounted on an axis.

It was formerly supposed that, when gunpowder is fired, the whole of the oxygen of the potassic nitrate is transferred to the carbon, forming carbonic anhydride, the sulphur combining with the potassium and the nitrogen being set free. There is no doubt that this reaction does take

place to a considerable extent, and that the large volume of gas thus produced, and still further expanded by the very high temperature, sufficiently accounts for the explosive effects. But recent investigations by Bunsen, Karolyi, and others, have shown that the actual products of the combustion of gunpowder are much more complicated than this theory would indicate, a very large number of products being formed, and a considerable portion of the oxygen being transferred to the potassic sulphide, converting it into sulphate, which, in fact, is found to constitute the chief portion of the solid residue and of the smoke formed by the explosion.

205. *Potassic Chlorate*. — This salt, KClO_3 , is soluble in about 20 parts of cold and 2 of boiling water; the crystals are anhydrous, flat, and tabular; in taste it somewhat resembles nitre. When heated, it gives off the whole of its oxygen gas and leaves potassic chloride.

This salt deflagrates violently with combustible matter, explosion often occurring by friction or blows. When about one grain-weight of chlorate and an equal quantity of sulphur are rubbed in a mortar, the mixture explodes with a loud report; hence it cannot be used in the preparation of gunpowder instead of the nitrate. Potassic chlorate is now a large article of commerce, being employed, together with phosphorus, in making friction matches.

206. *Potassic Carbonates*. — Potassium forms two well-defined carbonates: a normal or neutral carbonate, K_2CO_3 ; and an acid salt containing KHCO_3 .

Potassium-salts of vegetable acids are found in all plants. The potassium is derived from the soil, which, when capable of supporting vegetable life, always contains that substance. When plants are burned, the organic acids are destroyed, and the potassium is left in the state of carbonate.

It is by these indirect means that the neutral carbonate, and, in fact, nearly all the salts of potassium, are obtained.

The great natural depository of the alkali is the felspar of granitic and other unstratified rocks, where it is combined with silica, and in an insoluble state. All attempts at manufacturing it on a large scale from this source have failed ; but recent experiments indicate that the object may be accomplished by fusing potassic rocks with a mixture of calcic carbonate and fluoride. There are, however, natural processes at work, by which the potash is constantly separated from these rocks. Under the influence of atmospheric agencies, the rocks disintegrate into soils, and as the alkali acquires solubility, it is gradually taken up by plants, and accumulates in them in a condition highly favorable to its subsequent applications.

Potassium-salts are always most abundant in the green and tender parts of plants, as may be expected, since from these the evaporation of nearly pure water takes place to a large extent ; the solid timber of forest trees contains comparatively little.

In preparing the salt on an extensive scale, the ashes are subjected to a process called *lixiviation* ; they are put into a large cask or tun, having an opening near the bottom, stopped by a plug, and a quantity of water is added. After some hours the liquid is drawn off, and more water added, that the whole of the soluble matter may be removed. The weakest solutions are poured upon fresh quantities of ash, in place of water. The solutions are then evaporated to dryness, and the residue calcined, to remove a little brown organic matter ; the product is the crude *potash* or *pearlash* of commerce, of which very large quantities are prepared in Russia and America. This salt is very impure ; it contains potassic silicate, sulphate, chloride, etc.

The purified potassic carbonate of pharmacy is prepared from the crude article by adding an equal weight of cold water, agitating and filtering ; most of the foreign salts are,

from their inferior degree of solubility, left behind. The solution is then boiled down to a very small bulk, and suffered to cool, when the carbonate separates in small crystals containing 2 molecules of water, $K_2CO_3 \cdot 2H_2O$; these are drained from the mother-liquor, and then dried in a stove.

A still purer salt may be obtained by exposing to a red-heat purified cream of tartar (acid potassic tartrate), and separating the carbonate by solution in water and crystallization, or evaporation to dryness.

Potassic carbonate is extremely deliquescent, and soluble in less than its own weight of water; the solution is highly alkaline to test-paper. It is insoluble in alcohol. By heat the water of crystallization is driven off, and by a temperature of full ignition the salt is fused, but not otherwise changed. This substance is largely used in the arts, and is a compound of great importance.

The *acid potassic carbonate* is commonly called *bicarbonate of potash*. When a stream of carbonic acid gas is passed through a cold solution of neutral potassic carbonate, the gas is rapidly absorbed, and a white, crystalline substance separated, which is the acid salt. It is collected, pressed, re-dissolved in warm water, and the solution left to crystallize.

Acid potassic carbonate is much less soluble than the neutral carbonate; it requires for that purpose 4 parts of cold water. The solution is nearly neutral to test-paper, and has a much milder taste than the normal salt. When boiled, it gives off carbonic anhydride. The crystals, which are large and beautiful, derive their form from a monoclinic prism. They are decomposed by heat, water and carbonic anhydride being evolved, and neutral carbonate left behind. $2KHCO_3 = K_2CO_3 + H_2O + CO_2$.

207. *Potassic Sulphates*. — Potassium forms a normal or neutral sulphate and an acid sulphate.

Normal potassic sulphate, or *dipotassic sulphate*, K_2SO_4 , is obtained by neutralizing with crude potassic carbonate the acid residue left in the retort when nitric acid is prepared. The solution yields, on cooling, hard, transparent crystals of the neutral sulphate, which may be re-dissolved in boiling water, and re-crystallized.

Potassic sulphate is soluble in about 10 parts of cold, and in a much smaller quantity of boiling water; it has a bitter taste, and is neutral to test-paper. The crystals are combinations of rhombic pyramids and prisms. They are anhydrous, and decrepitate when suddenly heated, which is often the case with salts containing no water of crystallization. They are quite insoluble in alcohol.

Acid potassic sulphate or *monopotassic sulphate*, $KHSO_4$, is commonly called *bisulphate of potash*. To obtain this salt the neutral sulphate in powder is mixed with half its weight of oil of vitriol, and the whole evaporated quite to dryness in a platinum vessel, placed under a chimney; the fused salt is dissolved in hot water, and left to crystallize. The crystals have the figure of flattened rhombic prisms, and are much more soluble than the neutral salt, requiring only twice their weight of water at 15.5° , and less than half that quantity at 100° . The solution has a sour taste and a strongly acid reaction.

208. *Potassic Sulphides, etc.* — Potassium heated in sulphur vapor burns with great brilliancy. It unites with sulphur in five different proportions, forming the compounds K_2S , K_2S_2 , K_2S_3 , K_2S_4 , K_2S_5 ; also a sulphhydrate, KHS.

Liver of sulphur, or *hepar sulphuris*, is a name given to a brownish substance, sometimes used in medicine, made by fusing together different proportions of potassic carbonate and sulphur. It is a variable mixture of the two higher sulphides with potassic hyposulphite and sulphate.

SODIUM.

209. *Its History, Preparation, etc.* — Sodium is a very abundant element, and very widely diffused. It occurs in large quantities as *chloride*, in rock-salt, sea-water, salt-springs, and many other mineral waters; more rarely as *carbonate*, *borate*, and *sulphate*, in solution or in the solid state, and as *silicate* in many minerals.

Metallic sodium was obtained by Davy soon after the discovery of potassium, and by similar means. Gay-Lussac and Thénard afterwards prepared it by decomposing sodic hydrate with metallic iron at a white heat; and Brunner showed that it may be prepared with much greater facility by distilling a mixture of sodic carbonate and charcoal.

The preparation of sodium by this last-mentioned process is much easier than that of potassium, not being complicated, or only to a slight extent, by the formation of secondary products. Within the last few years it has been considerably improved by Deville and others, and carried out on the manufacturing scale; sodium being now employed in considerable quantity as a reducing agent, especially in the manufacture of aluminium and magnesium, and in the silver amalgamation process.

210. *Sodic Chloride (Common Salt).* — This very important substance, NaCl , is found in many parts of the world in solid beds or irregular strata of immense thickness, as in Cheshire, Spain, Galicia, and many other localities. An inexhaustible supply exists also in the waters of the ocean, and large quantities are obtained from saline springs.

Rock-salt is almost always too impure for use. If no natural brine-spring exists, an artificial one is formed by sinking a shaft into the rock-salt, and, if necessary, introducing water. This, when saturated, is pumped up, and evaporated more or less rapidly in large iron pans. As the

salt separates, it is removed from the bottom of the vessel by means of a scoop, pressed while still moist into moulds, and then transferred to the drying-stove. When large crystals are required, as for the coarse-grained *bay-salt* used in curing provisions, the evaporation is slowly conducted. Common salt is apt to be contaminated with magnesian chloride.

Sodic chloride, when pure, is not deliquescent in moderately dry air. It crystallizes in anhydrous cubes, which are often grouped together into pyramids, or steps. It requires about $2\frac{1}{2}$ parts of water at 60° F. for solution, and its solubility is not sensibly increased by heat; it dissolves to some extent in spirit of wine, but is nearly insoluble in absolute alcohol. It melts at a red heat, and is volatile at a still higher temperature. Its uses are well known, and need not be described here.

Sodic iodide and *bromide* much resemble the corresponding potassium compounds; they crystallize in cubes which are anhydrous and very soluble in water.

211. *Sodic Oxides*. — Sodium forms a monoxide, Na_2O , and a dioxide, Na_2O_2 ; also a hydrate corresponding to the former.

Sodic monoxide or *anhydrous soda* is produced, together with the dioxide, when sodium burns in the air, and may be obtained pure by exposing the dioxide to a very high temperature; or by heating sodic hydrate with an equivalent quantity of sodium: $2\text{NaHO} + \text{Na}_2 = 2\text{Na}_2\text{O} + \text{H}_2$. It is a gray mass, which melts at a red heat, and volatilizes with difficulty.

Sodic hydrate or *caustic soda* is prepared by decomposing a somewhat dilute solution of sodic carbonate with calcic hydrate. $\text{Na}_2\text{CO}_3 + \text{Ca}(\text{HO})_2 = \text{CaCO}_3 + 2\text{NaHO}$.

The solid hydrate is a white fusible substance, very similar in properties to potassic hydrate. It is deliquescent, but dries up again after a time in consequence of the absorption

of carbonic acid. The solution is highly alkaline, and a powerful solvent for animal matter. It is used in large quantity for making soap.

Sodium, when heated to about 200° in a current of dry air, absorbs oxygen, and is converted into *sodic dioxide*. This substance is white, but becomes yellow when heated, which tint it again loses on cooling.

212. *Sodic Carbonate or Soda-Ash*. — Before the French Revolution, the Continental nations of Europe derived their soda-ash from Spain, where it was made from the ashes of certain marine plants, which were extensively cultivated for this purpose. The soda-ash obtained from the ashes of these plants was called *barilla*.

In England, the soda-ash used was mainly obtained from the ashes of a sea-weed called *kelp*, which grows abundantly on the north and west coast of Ireland, and on the west coast and the islands of Scotland.

One of the first effects of the war of the French Revolution was to cut off the supply of alkali from Spain. About this time, a French chemist, Le Blanc, discovered a process by which sodic carbonate, or soda-ash, Na_2CO_3 , could be obtained from common salt, or *sodic chloride*, NaCl . This process became publicly known through a commission appointed, during the first year of the Republic, to investigate the subject of alkali manufacture. As it met with their approval, it was soon carried into execution.

The method discovered by Le Blanc is the same as that now used in the making of soda-ash, which has come to be conducted on a stupendous scale.

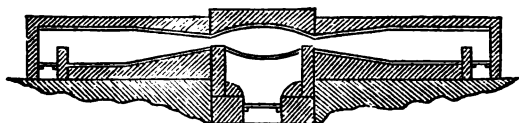
The manufacture of sodic carbonate from sodic chloride may be divided into two stages :—

(1.) Manufacture of sodic sulphate, or *salt-cake*, from sodic chloride ; called the *salt-cake process*.

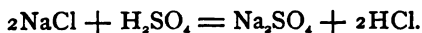
(2.) Manufacture of sodic carbonate, or soda-ash, from salt-cake ; called the *soda-ash process*.

(1.) *Salt-Cake Process*. — This consists in the decomposition of salt, by means of sulphuric acid. This is effected in a furnace, called the *salt-cake furnace*, a section of which is represented in Figure 50. It consists of a large cov-

Fig. 50.



ered iron pan, placed in the centre of the furnace, and heated by a fire placed underneath; and two *roasters*, or reverberatory furnaces, placed one at each side, on the hearths of which the salt is completely decomposed. The charge of half a ton of salt is first placed in the iron pan, and the requisite quantity of sulphuric acid allowed to run in upon it. Muriatic acid is evolved, and escapes through a flue with the products of combustion into towers, or *scrubbers*, filled with coke or bricks moistened with a stream of water; the acid vapors are thus condensed, while the smoke and heated air pass up the chimney. The reaction is as follows:—

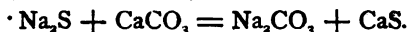


After the mixture of salt and acid has been heated for some time in the iron pan, and has become solid, it is raked out upon the hearths of the *roasters*, where the flame and heated air of the fire complete the decomposition into sodic sulphate and muriatic acid.

(2.) *Soda-Ash Process*. — This consists (1.) in the preparation of the sodic carbonate, and (2.) in the separation and purification of the same. The first chemical change which the salt-cake undergoes is its reduction to *sodic sulphide*, by heating it with powdered coal:—



The second decomposition is the conversion of the sodic sulphide into sodic carbonate, by heating it with chalk or limestone (calcic carbonate):—



These two reactions are, in practice, carried on at once; a mixture of ten parts of salt-cake, ten parts of chalk or limestone, and seven and a half parts of coal, being heated in a reverberatory furnace, called the *balling furnace*, until it fuses, and the decomposition is complete, when it is raked out into iron wheelbarrows to cool. This process is generally called the *black-ash process*, from the color of the fused mass.

The next operation consists in the separation of the sodic carbonate from the insoluble calcic sulphide and other impurities. This is easily accomplished by *lixiviation*, or dissolving the former salt out in water. On evaporating down the solution, for which the waste heat of the balling furnace is used, and calcining the residue, the soda-ash of commerce is obtained.

No less than 200,000 tons of common salt are annually consumed in the alkali works of Great Britain, for the preparation of nearly the same weight of soda-ash, the value of which is about £2,000,000.

The ordinary crystals of sodic carbonate contain ten molecules of water; but the same salt may be obtained with fifteen, nine, or seven molecules, or sometimes with only one. The common form of the crystals is derived from an oblique rhombic prism; they effloresce in dry air, and crumble to a white powder. Heated, they fuse in their water of crystallization: when the latter has been expelled, and the dry salt exposed to a full red heat, it melts without undergoing change. The common crystals dissolve in two parts of cold, and in less than their own weight of boiling water; the solution has a strong, disagreeable, alkaline taste, and a powerfully alkaline reaction.

213. *Acid Sodic Carbonate*. — This salt, NaHCO_3 , is commonly called *bicarbonate of soda*. It is prepared by passing carbonic acid gas into a cold solution of the neutral carbonate, or by placing the crystals in an atmosphere of the gas, which is rapidly absorbed, while the crystals lose the greater part of their water, and pass into the new compound.

Prepared by either process, it is a crystalline white powder, which cannot be redissolved in warm water without partial decomposition. It requires 10 parts of water at 15.5° for solution; the liquid is feebly alkaline to test-paper, and has a much milder taste than that of the simple carbonate. By exposure to heat, the salt is converted into neutral carbonate.

214. *Sodic Sulphate*. — This substance, Na_2SO_4 , commonly called *Glauber's salt*, may be prepared by adding dilute sulphuric acid, to saturation, to a solution of sodic carbonate. It crystallizes in forms derived from an oblique rhombic prism; the crystals contain 10 molecules of water,* and are efflorescent. They are soluble in twice their weight of cold water, and rapidly increase in solubility as the temperature of the liquid rises to 33° , when a maximum is reached, 100 parts of water dissolving 117.9 parts of the salt, corresponding to 52 parts anhydrous sodic sulphate. When the salt is heated beyond this point the solubility diminishes, and a portion of sulphate is deposited. A warm saturated solution, evaporated at a high temperature, deposits opaque prismatic crystals, which are anhydrous. The salt has a slightly bitter taste. Mineral springs sometimes contain it, as that at Cheltenham, England.

215. *Sodic Hyposulphite*. — There are several modes of procuring this salt, $\text{Na}_2\text{S}_2\text{O}_3$, which is now much used for photographic purposes and as an antichlore (134). One

* This *water of crystallization* (124) is expressed in the symbol of the compound thus: $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$.

of the best is to form neutral *sodic sulphite*, by passing a stream of well-washed sulphurous anhydride into a strong solution of sodic carbonate, and then to digest the solution with sulphur at a gentle heat during several days. By careful evaporation at a moderate temperature, the salt is obtained in large and regular crystals, which are very soluble in water.

216. *Sodic Nitrate*. — This salt, NaNO_3 , sometimes called *cubic nitre* or *Chili saltpetre*, occurs native and in enormous quantity at Tarapaca in Northern Peru, where it forms a regular bed, of great extent, along with gypsum, common salt, and remains of recent shells. The pure salt commonly crystallizes in rhombohedrons. It is deliquescent, and very soluble in water. Sodic nitrate is employed for making nitric acid, but cannot be used for gunpowder, as the mixture burns too slowly, and becomes damp in the air. It has been lately used with some success in agriculture as a superficial manure or top-dressing; also for preparing potassic nitrate (203).

217. *Sodic Phosphates*. — The composition and chemical relations of these salts have already been explained (156).

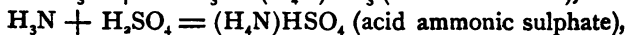
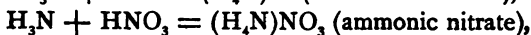
218. *Sodic Borate (Borax)*. — This salt, $\text{Na}_2\text{O}(\text{B}_2\text{O}_3)_2 \cdot 10\text{H}_2\text{O}$, occurs in the waters of certain lakes in Thibet and Persia; it is imported in a crude state from the East Indies under the name of *tincal*. Much borax is now, however, manufactured from the native boric acid of Tuscany, and also from a native calcic borate called *hayesine*, which occurs in Southern Peru. Borax crystallizes in six-sided prisms, which effloresce in dry air, and require 20 parts of cold and 6 of boiling water for solution. Exposed to heat, the 10 molecules of water of crystallization are expelled; and at a higher temperature the salt fuses, and assumes a glassy appearance on cooling. In this state it is much used for blowpipe experiments, the metallic oxides dissolving in it to transparent beads, many of which are

distinguished by characteristic colors. Although by constitution an acid salt, borax has an alkaline reaction to test-paper. It is used in the arts for soldering metals, its action keeping the metallic surfaces clean by dissolving the oxides. It is sometimes used in the *glaze* with which stone-ware is covered.

219. *Sodic Sulphide*. — Sodic sulphide, Na_2S , is supposed to enter into the composition of the beautiful pigment *ultramarine*, which is prepared from the *lapis lazuli*, and is now imitated artificially. An intimate mixture of 37 parts kaolin, 15 sodic sulphate, 22 sodic carbonate, 18 sulphur, and 8 charcoal, is heated from twenty-four to thirty hours in large crucibles. The product thus obtained is again heated in cast-iron boxes at a moderate temperature till the required tint is obtained. After being finely pulverized, washed, and dried, it constitutes commercial ultramarine. The composition of this color varies, and its true constitution is not known.

AMMONIUM.

220. *Its Nature and Compounds*. — The ammonia salts are most conveniently studied in this place, on account of their close analogy to those of potassium and sodium. These salts are formed by the direct union of ammonia, H_3N , with acids, and they may be regarded as compounds of acid radicals, Cl , NO_3 , SO_4 , etc., with a basic radical, H_4N , called *ammonium*, which plays in these salts the same part which potassium and sodium play in their respective compounds; thus:—



The radical H_4N is not capable of existing in the free state, inasmuch as it contains an uneven number of monad atoms ; it is simply the residue which is left on removing the atom of chlorine from the saturated molecule $\text{H}_4\text{N}^\vee\text{Cl}$. Whether the double molecule H_8N_2 , or $\text{H}_4\text{N}=\text{N}=\text{H}_4$, has a separate existence is a different question. Ammonium appears, indeed, to be capable of forming an amalgam with mercury ; but even in this state it is quickly resolved into ammonia and free hydrogen.

A simple method of preparing this *ammoniacal amalgam* is the following : A little mercury is put into a test-tube with a grain or two of potassium or sodium, and gentle heat applied ; combination ensues, attended by heat and light. When cold, the fluid amalgam is covered with a strong solution of sal-ammoniac. The production of an ammoniacal amalgam instantly commences, the mercury increasing prodigiously in volume, and becoming quite pasty. The increase of weight is, however, quite trifling : it varies from .0008 to .0012. If left to itself, the amalgam quickly decomposes into liquid mercury, ammonia, and hydrogen. It is quite possible, indeed, that the so-called amalgam may be nothing more than mercury which has absorbed a certain quantity of these gases ; just as silver, when heated to a very high temperature, is capable of taking up about twenty times its volume of oxygen gas, which it gives up again on cooling.

Experiments lately made by Weyl afford somewhat stronger evidence in favor of the separate existence of ammonium. When lumps of pure bright sodium are placed at one end of a bent tube, a quantity of argentic chloride previously saturated with ammonia gas at the other, the tube then sealed, the end containing the argentic chloride heated in a bath of calcic chloride, and the other end immersed in cold water, the sodium swells up, and is converted into a liquid, which is copper-red by perpendicularly

reflected, greenish-yellow by obliquely reflected light, blue in thin films by transmitted light. This liquid is *sodammonium*, $\text{H}_6\text{N}_2\text{Na}_2$; that is, ammonium, H_8N_2 , with two of its hydrogen atoms replaced by sodium. As the argentic chloride cools, and the ammonia gas is reabsorbed, the sodammonium decomposes and pure sodium remains behind, having a dull surface and spongy texture. By again heating the argentic chloride the compound may be reproduced any number of times.

Potassammonium, $\text{H}_6\text{N}_2\text{K}_2$ (?), is prepared like sodammonium, and exhibits similar properties.

Other *metallammoniums* may be produced by the decomposition of sodammonium or potassammonium.

But whether ammonium has any separate existence or not, it is quite certain that many ammoniacal salts are isomorphous with those of potassium; and if from any two of the corresponding salts, as the nitrates, KNO_3 and $(\text{H}_4\text{N})\text{NO}_3$, we subtract the radical NO_3 , common to the two, there remain the metal K and the group H_4N , which are, therefore, supposed to be isomorphous.

221. *Ammonic Chloride (Sal-ammoniac)*. — Sal-ammoniac, H_4NCl , was formerly obtained from Egypt,* but it is now largely manufactured from the ammoniacal liquid of the gas-works, and from the condensed products of the distillation of bones and other animal refuse, in the preparation of animal charcoal.

Sublimed sal-ammoniac has a fibrous texture; it is tough, and difficult to powder. It has a sharp saline taste, and is soluble in 2.75 parts of cold and in a much smaller quantity of hot water. By heat, it is sublimed without decomposition. It forms double salts with the chlorides of magnesium, nickel, cobalt, manganese, zinc, and copper.

* *Ammonium* takes its name from this salt, which was called *sal-ammoniac* because it was found near the temple of Jupiter Ammon in Libya.

222. *Ammonic Nitrate*. — This salt, $(\text{H}_4\text{N})\text{NO}_3$, is easily prepared by adding ammoniac carbonate to slightly diluted nitric acid until it is neutralized. By slow evaporation at a moderate temperature it crystallizes in six-sided prisms, like those of potassic nitrate; but, as usually prepared, it forms a fibrous and indistinct crystalline mass.

Ammonic nitrate dissolves in two parts of cold water, producing considerable depression of temperature; it is but feebly deliquescent, and deflagrates like nitre on contact with heated combustible matter (203).

223. *Ammonic Sulphate*. — This salt, $(\text{H}_4\text{N})_2\text{SO}_4$, may be prepared by neutralizing ammoniac carbonate with sulphuric acid, or, on a large scale, by adding sulphuric acid in excess to the coal-gas liquor just mentioned, and purifying the product by suitable means. It is soluble in 2 parts of cold water, and crystallizes in long, flattened, six-sided prisms.

224. *Ammonic Carbonates*. — According to Sainte-Claire Deville, there are only two ammoniac carbonates of definite composition, viz. :—

(1.) *Mono-ammonic carbonate*, $(\text{H}_4\text{N})\text{HCO}_3$, commonly called *bicarbonate*, or *acid carbonate of ammonia*. — This salt is obtained by saturating an aqueous solution of ammonia with carbonic anhydride. It forms large crystals belonging to the trimetric system. It dissolves in 8 parts of cold water, the solution decomposing gradually at ordinary temperatures, quickly when heated above 30° with evolution of ammonia.

It has been found native in considerable quantity in the deposits of guano on the western coast of Patagonia, in white crystalline masses, having a strong ammoniacal odor.

(2.) *Tetrammonio-dihydric Carbonate*, $(\text{H}_4\text{N})_4\text{H}_2(\text{CO}_3)_3$. — This salt, commonly called *sesquicarbonate of ammonia*, is obtained by dissolving the commercial carbonate in strong aqueous ammonia, at about 30° , and crystallizing the solution. It forms large transparent rectangular prisms,

having their summits truncated by octohedral faces. These crystals decompose very rapidly in the air, giving off water and ammonia, and being converted into mono-ammonic carbonate.

Commercial carbonate of ammonia (*sal volatile, salt of hartshorn*) consists of sesquicarbonate more or less pure. It is prepared on the large scale by the dry distillation of bones, hartshorn, and other animal matter, and is purified by subliming it once or twice with animal charcoal in cast-iron vessels, over which glass receivers are inverted.

225. *Ammonic Sulphides*. — Several of these compounds exist, and may be formed by distilling with sal-ammoniac the corresponding sulphides of potassium or sodium.

Ammonic sulphhydrate, $(\text{H}_4\text{N})\text{HS}$, is a compound of great practical utility. It is obtained by saturating a solution of ammonia with well-washed hydric sulphide gas, until no more of the latter is absorbed. The solution is nearly colorless at first, but becomes yellow after a time, without, however, suffering material injury, unless it has been exposed to the air. It gives precipitates with most metallic solutions, which are very often characteristic, and is of great service in analytical chemistry.

LITHIUM.

226. *Its Preparation, Properties, etc.* — Lithium is found in a few minerals, and sometimes occurs in minute quantities in mineral springs.

The metal is obtained by fusing pure lithic chloride in a small thick porcelain crucible, and decomposing the fused chloride by electricity. It is a white metal like sodium, and very oxidizable. It fuses at 180° . Its specific gravity is 0.59; it is, therefore, the lightest solid element known.

The salts of lithium color the outer flame of the blow-pipe carmine-red.

CÆSIUM AND RUBIDIUM.

227. *Their History, etc.* — These two metals were discovered by Bunsen and Kirchhoff by means of their spectrum apparatus : the former in 1860 and the latter in 1861. They are widely diffused in nature, but always occur in very small quantities. They have been detected in many mineral waters, as well as in some minerals ; they have also been found in the alkaline ashes of the beet-root. Both metals are closely analogous to potassium in their deportment, and cannot be distinguished from that metal or from each other, either by reagents or before the blowpipe.

SILVER.

228. *Its Ores and their Reduction.* — Silver is found in the metallic state as sulphide (in union with sulphides of antimony and arsenic), also as chloride, iodide, and bromide. Among the principal silver-mines may be mentioned those of the Hartz Mountains in Germany, of Kongsberg in Norway, and, more particularly, of the Andes in both North and South America.

The greater part of the silver of commerce is extracted from ores so poor as to render any process of *smelting* or fusion inapplicable, even where fuel could be obtained, and this is often difficult to be procured. Recourse, therefore, is had to another method, — that of *amalgamation*, — founded on the easy solubility of silver and many other metals in metallic mercury.

The amalgamation process adopted in Germany — which differs somewhat from that in use in America — is as follows : The ore is crushed to powder, mixed with a quantity of common salt, and roasted at a low red heat in a suitable furnace, by which treatment any argentic sulphide present is converted into chloride. The mixture of earthy matter,

oxides of iron and copper, soluble salts, argentic chloride, and metallic silver, is sifted and put into large barrels made to revolve on axes, with a quantity of water and scraps of iron ; and the whole is agitated together for some time, during which the iron reduces the argentic chloride to the state of metal. A certain proportion of mercury is then introduced, and the agitation repeated ; the mercury dissolves out the silver, together with gold (if there be any), metallic copper, and other substances, forming a liquid amalgam easily separable from the thin mud of earthy matter by subsidence and washing. This amalgam is strained through a strong linen cloth, and the solid portion exposed to heat in a kind of retort, by which the remaining mercury is distilled off and the silver left behind in an impure state.

A considerable quantity of silver is obtained from argentiferous galena ; in fact, almost every specimen of native plumbic sulphide is found to contain traces of this metal. When the proportion rises to a certain amount, it becomes worth extracting. The ore is reduced in the usual manner, the whole of the silver remaining with the lead ; the latter is then remelted in a large vessel, and allowed to cool slowly until solidification commences. The portion which first crystallizes is nearly pure lead, the alloy with silver being *more fusible than lead itself* ; by particular management this is drained away, and is found to contain nearly the whole of the silver. This rich mass is next exposed to a red heat on the shallow hearth of a furnace, while a stream of air is allowed to flow in upon it ; oxidation takes place with great rapidity, the fused oxide or *litharge* being constantly swept from the metal by the blast. When the greater part of the lead has been removed, the residue is transferred to a *cupel* or shallow dish made of bone ashes, and again heated ; the rest of the lead is now oxidized, and sinks in a melted state into the porous vessel, while the silver, almost chemically pure, remains behind.

229. *Its Properties.* — Pure silver has a most perfect white color and a high degree of lustre ; it is exceedingly malleable and ductile, and is probably the best conductor both of heat and electricity known. Its specific gravity is 10.5. In hardness it is between gold and copper. It melts at a bright red heat, about 1873° F. (1023° C.), according to the observations of Mr. Daniell. Silver is unalterable by air and moisture ; it refuses to oxidize at any temperature, but possesses the extraordinary property already noticed of absorbing many times its volume of oxygen when strongly heated in an atmosphere of that gas, or in common air. The oxygen is again disengaged at the moment of solidification, and gives rise to the peculiar arborescent appearance often remarked on the surface of masses of pure silver. The addition of 2 per cent of copper is sufficient to prevent the absorption of oxygen. Silver oxidizes when heated with fusible silicious matter, as glass, which it stains yellow or orange, from the formation of a silicate. It is little attacked by muriatic acid ; boiling oil of vitriol converts it into sulphate, with evolution of sulphurous oxide ; nitric acid, even dilute and in the cold, dissolves it readily. The tarnishing of surfaces of silver exposed to the air is due to hydric sulphide, the metal having a strong attraction for sulphur.

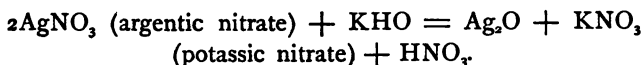
The economical uses of silver are many ; it is admirably adapted for culinary and other similar purposes, not being attacked in the slightest degree by any of the substances used for food. It is necessary, however, in these cases, to diminish the softness of the metal by a small addition of copper. The standard silver of England contains 222 parts of silver and 18 parts of copper.

230. *Argentio Chloride.* — This compound, AgCl , is almost invariably produced when a soluble silver salt and a soluble chloride are mixed. It falls as a white curdy precipitate, quite insoluble in water and nitric acid ; but

one part of silver chloride is soluble in 200 parts of muriatic acid when concentrated, and in about 600 parts when diluted with double its weight of water. When heated it melts, and on cooling becomes a grayish crystalline mass, which cuts like horn; it is found native in this condition, constituting the *horn-silver* of the mineralogist. It is decomposed by light, both in the dry and in the wet state, very slowly if pure, and quickly if organic matter be present; it is reduced also when put into water with metallic zinc or iron. It dissolves with great ease in ammonia and in a solution of potassic cyanide.

231. *Argentio Iodide*. — This substance, AgI , is a pale-yellow insoluble precipitate, produced by adding argentic nitrate to potassic iodide; it is insoluble, or nearly so, in ammonia, and in this respect forms an exception to the silver-salts in general. Hydric iodide converts argentic chloride into iodide. The *bromide* of silver very closely resembles the chloride.

232. *Argentio Oxide*. — There are three oxides of silver, of which only the *monoxide* or *argentio oxide*, Ag_2O , can be regarded as a well-defined compound. This is a powerful base, yielding salts isomorphous with those of the alkali metals. It is obtained as a pale-brown precipitate on adding caustic potash to a solution of argentic nitrate:—



It is very soluble in ammonia, and is dissolved also to a small extent by pure water; the solution is alkaline. It neutralizes acids completely, and forms, for the most part, colorless salts. It is decomposed by a red heat, with evolution of oxygen, spongy metallic silver being left; the sun's rays also effect its decomposition to a small extent.

233. *Argentio Nitrate*. — This salt, AgNO_3 , is prepared.

by dissolving silver in nitric acid, and evaporating the solution to dryness, or until it is strong enough to crystallize on cooling. The crystals are colorless, transparent, anhydrous tables, soluble in an equal weight of cold and in half that quantity of boiling water; they also dissolve in alcohol. They fuse when heated, like those of nitre, and at a high temperature suffer decomposition. The *lunar caustic* of the surgeon is argentic nitrate which has been melted and poured into a cylindrical mould. The salt blackens when exposed to light, more particularly if organic matters of any kind are present, and is frequently employed in hair-dyes. It is used also in the *indelible ink* made for marking linen. The black stain has been thought to be metallic silver; it may possibly be an oxide of the metal.

234. *Argentic Sulphate*. — The sulphate, Ag_2SO_4 , may be prepared by boiling together oil of vitriol and metallic silver, or by precipitating a concentrated solution of argentic nitrate with an alkaline sulphate. It dissolves in 88 parts of boiling water, and separates in great measure in the crystalline form on cooling, having but a feeble degree of solubility at a low temperature.

235. *Argentic Sulphide*. — This compound, Ag_2S , is a soft, gray, and somewhat malleable substance, found native in the crystallized state, and easily produced by melting together its constituents, or by precipitating a solution of silver with hydric sulphide. It is a strong sulphur-base, and combines with the sulphides of antimony and arsenic.

236. *Ammonia-Compound of Silver (Berthollet's Fulminating Silver)*. — When precipitated argentic oxide is digested in ammonia, a black substance is produced, possessing extremely dangerous explosive properties. While moist, it explodes when rubbed with a hard body, but when dry the touch of a feather is sufficient. The ammonia retains some of this substance in solution, and deposits it in small crystals by spontaneous evaporation. A similar compound

exists containing auric oxide. These bodies contain an oxide of an easily reducible metal and ammonia; the attraction between the two constituents of the substance is very feeble, while that between the oxygen of the one and the hydrogen of the other is very powerful. The explosion is caused by the sudden evolution of nitrogen gas and aqueous vapor, the metal being set free.

THALLIUM.

237. *Its History, Properties, etc.* — Thallium was discovered by means of spectral analysis in Lipari sulphur and in the soot of furnaces in which iron pyrites (FeS_2) are roasted. It has much the appearance of lead, but is heavier, its specific gravity being 11.85. It is very soft and malleable, and quite ductile. It soon oxidizes in the air. When strongly heated in oxygen, it takes fire and burns with a green flame.

Its chief oxide, Tl_2O , dissolves to some extent in water, yielding a caustic alkaline liquid.

238. *The Monad or Alkali Group of Metals.* — The metals potassium, sodium, (ammonium), lithium, cæsium, and rubidium have strongly marked family features. They are all soft, easily fusible, volatile at high temperature, and have the lustre of silver. They have a strong affinity for oxygen, and decompose water at the ordinary temperature. They all form basic oxides, but never acid oxides. Their hydrates are very caustic and intensely alkaline bodies, which cannot be decomposed by heat. Each metal forms but one chloride, bromide, and iodide. Nearly all their salts are soluble in water.

Silver and thallium are classed with the metals of this group, simply because they are like them in the combining power of their atoms. These metals are all univalent.

METALS OF THE ALKALINE EARTHS.

CALCIUM.

239. *Its History and Properties.* — Calcium is one of the most abundant and widely diffused of the metals, though it is never found in the free state. As carbonate, it occurs in a great variety of forms, constituting, as limestone, entire mountain ranges. Calcium was obtained in an impure state by Davy, by means similar to those adopted for the preparation of lithium.

Calcium is a light-yellow metal of sp. gr. 1.5778. It is about as hard as gold, very ductile, and may be cut, filed, or hammered out into plates as thin as the finest paper. It tarnishes slowly in dry, more quickly in damp air, decomposes water quickly, and is still more rapidly acted upon by dilute acids. Heated on platinum foil over a spirit lamp, it burns with a bright flash; with a brilliant light also when heated in oxygen or chlorine gas, or in vapor of bromine, iodine, or sulphur.

240. *Calcic Chloride.* — This salt, CaCl_2 , is usually prepared by dissolving marble in muriatic acid. It separates from a strong solution in colorless, prismatic, and exceedingly deliquescent crystals, which contain 6 molecules of water. By heat this water is expelled, and by a temperature of strong ignition the salt is fused. The crystals reduced to powder are employed in the production of artificial cold by being mixed with snow or powdered ice; and the chloride, strongly dried or in the fused state, is of great practical use in drying gases, for which purpose the latter are slowly transmitted through tubes filled with fragments of the salt.

• 241. *Calcic Fluoride (Fluor-Spar).* — This substance, CaF_2 , is important as the most abundant natural source of hydric fluoride and the other fluorides. It occurs beauti-

fully crystallized, of various colors, in lead-veins, the crystals having commonly the cubic, but sometimes the octohedral form. Some varieties, when heated, emit a greenish, and some a purple, phosphorescent light. The fluoride is quite insoluble in water, and is decomposed by oil of vitriol (116).

242. *Calcic Monoxide, or Lime.*—This extremely important compound, CaO , may be obtained in a state of considerable purity by heating to full redness for some time fragments of the black bituminous marble of Derbyshire or Kilkenny. If required absolutely pure, it must be made by igniting to whiteness, in a platinum crucible, an artificial calcic carbonate, prepared by precipitating the nitrate with ammoniac carbonate. Lime in an impure state is prepared on a large scale, for building and other purposes, by heating limestone (the carbonate) in kilns by means of coal mixed with the stone; the carbonic acid escapes, and *quicklime* or *caustic lime* remains. Pure lime is a white, infusible substance, which combines with water very readily, giving off great heat, and falling to a white powder called *calcic hydrate*, or *slaked lime*. The hydrate is slightly soluble in water, 1 part of it dissolving in 730 parts of cold, but only in 1,300 parts of boiling water, and forming lime-water, which, like the hydrate, has a great power of absorbing carbonic acid from the air. It is, indeed, partly owing to this property that the hardening or *setting* of mortars and cements made from lime is due. *Mortar* consists of a mixture of slaked lime and sand. A gradual combination of the lime with the silica occurs, and this helps to harden the mixture. *Hydraulic cement*, which hardens under water, is prepared by carefully heating an impure lime containing clay and silica; a compound silicate of lime and alumina appears to be formed on moistening the powder, which then solidifies, and is not acted upon by water. Lime is largely used in agriculture, its action being, (1) to destroy

the excess of vegetable matter contained in the soil; and (2) to liberate the potash for the use of the plants from heavy clay soils by decomposing the silicate.

243. *Calcic Carbonate*. — This salt, CaCO_3 , occurs most widely diffused as chalk, limestone, coral, and marble; many of those immense deposits being made up of the microscopic remains of minute sea-animals. The carbonate is almost insoluble in pure water; but readily dissolves when the water contains carbonic acid, and is deposited again, in crystals, as the gas escapes. In this way enormous masses of crystalline limestone are formed. Water charged with carbonic acid and calcic carbonate makes its way through the roof of limestone caverns, and, as the carbonic acid gradually escapes, the calcic carbonate is deposited in dependent masses, like icicles, termed *stalactites*; while the water, falling on the floor of the cavern before it has parted with all its carbonic acid and dissolved limestone, deposits a fresh portion of the crystalline matter, and thus a new growth, or *stalagmite*, gradually rises to meet the *stalactite* which hangs from the roof. In this way a natural pillar of limestone is formed.

244. *Calcic Sulphate*. — This substance, CaSO_4 , occurs in nature, combined with $2\text{H}_2\text{O}$, as *gypsum* or *alabaster*. It is soluble in 400 parts of water, and is a very common impurity in spring-water, giving rise to a *hardness* which cannot be removed by boiling. Gypsum, when moderately heated, loses its water, and is then called *plaster of Paris*; this, when moistened, takes up two atoms of water again and *sets* to a solid mass, and is therefore much used for making casts and moulds.

Artificial colored marbles, or *scagliola*, are frequently prepared by inserting pieces of natural stone in a soft stucco containing this substance, and polishing the surface when the cement has become hard. Calcic sulphate is one of the most common impurities of spring-water.

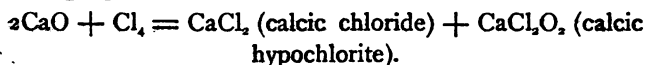
245. *Calcic Phosphates*. — A number of distinct calcic salts of phosphoric acid are known. Two *tribasic phosphates* or *orthophosphates*, $\text{Ca}''_3(\text{PO}_4)_2$ and $\text{Ca}''\text{H}(\text{PO}_4)$, are produced when the corresponding sodic salts are added in solution to calcic chloride; the first is slightly crystalline, and the second gelatinous. The earth of bones consists principally of what appears to be a combination of these two salts. Another orthophosphate, $\text{Ca}''\text{H}_2(\text{PO}_4)_2$, is formed by dissolving either of the preceding in phosphoric, muriatic, or nitric acid, and evaporating. It is the substance which yields phosphorus when heated with charcoal, in the ordinary process of manufacture before described. Calcic *pyrophosphates* and *metaphosphates* also exist. The mineral *apatite* is chiefly calcic phosphate.

246. *Chloride of Lime (Bleaching Powder)*. — When calcic hydrate, very slightly moist, is exposed to chlorine gas, the latter is eagerly absorbed, and a compound produced which has attracted a great deal of attention. This is the *bleaching powder* of commerce, now manufactured on an immense scale, for bleaching linen and cotton goods. When freshly and well prepared, it is a soft, white powder, which attracts moisture from the air, and exhales an odor sensibly different from that of chlorine. It is soluble in about 10 parts of water, the unaltered hydrate being left behind; the solution is highly alkaline, and bleaches feebly. When calcic hydrate is suspended in cold water, and chlorine gas transmitted through the mixture, the lime is gradually dissolved, and the same peculiar bleaching compound produced. The alkalis also, either caustic or carbonated, may by similar means be made to absorb a large quantity of chlorine, and give rise to corresponding compounds; such are the *disinfecting solutions* of Labarraque.

The most consistent view of the constitution of these compounds is that which supposes them to contain salts of *hypochlorous acid*, HClO , a substance as remarkable for

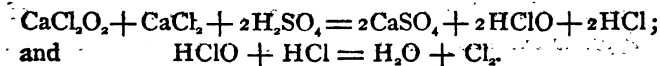
bleaching powers as chlorine itself ; and this opinion seems borne out by a careful comparison of the properties of the bleaching salts with those of the true hypochlorites. Hypochlorous acid can be actually obtained from good bleaching powder, by distilling it with dilute sulphuric or nitric acid, in quantity insufficient to decompose the whole ; when the acid is used in excess, chlorine is disengaged.

If this view be correct, calcic chloride must be formed simultaneously with the hypochlorite, as shown by the following equation :—



When the temperature of the calcic hydrate has risen during the absorption of the chlorine, or when the compound has been subsequently exposed to heat, its bleaching properties are impaired or altogether destroyed. It then contains calcic chlorate and chloride ; oxygen, in variable quantity, is usually set free. The same change seems to ensue from long keeping, even at the common temperature of the air. In an open vessel it is speedily destroyed by the carbonic acid of the air. Commercial bleaching powder thus constantly varies in value with its age, and with the care originally bestowed upon its preparation. The best may contain about 30 per cent of available chlorine, easily liberated by an acid, which is, however, far short of the theoretical quantity.

When this substance is employed for bleaching, the goods are first immersed in a dilute solution of chloride of lime, and then transferred to a vat containing dilute sulphuric acid. Decomposition ensues ; the calcium both of the hypochlorite and of the chloride is converted into sulphate, while the free hypochlorous and muriatic acids yield water and free chlorine :—



The chlorine thus disengaged in contact with the cloth causes the destruction of the coloring matter. This process is often repeated, it being unsafe to use strong solutions. White patterns are on this principle printed upon colored cloth, the figures being stamped with tartaric acid thickened with gum-water, and then the stuff immersed in the chloride bath, when the parts to which no acid has been applied remain unaltered, while the printed portions are bleached.

For purifying an offensive or infectious atmosphere, *as an aid to proper ventilation*, the bleaching powder is very convenient. The solution is exposed in shallow vessels, or cloths steeped in it are suspended in the apartment, when the carbonic acid of the air slowly decomposes it in the manner above described. An addition of a strong acid causes rapid disengagement of chlorine.

STRONTIUM.

247. *Its Preparation, etc.*—Strontium is usually described as a white metal, heavy, oxidizable in the air, and capable of decomposing water at common temperatures. Matthiessen states, however, that it has a dark-yellow color, and a specific gravity of 2.54.

248. *Strontia.*—*Strontic monoxide*, or *strontia*, SrO , is obtained by decomposing the nitrate by means of heat. It is a grayish, spongy substance, and when moistened with water forms a white hydrate, SrH_2O_2 .

249. *Strontic Chloride.*—The chloride, SrCl_2 , crystallizes in colorless needles or prisms, which are slightly deliquescent, and soluble in 2 parts of cold and a still smaller quantity of boiling water; they are also soluble in alcohol, and the solution, when kindled, burns with a crimson flame. The crystals contain 6 molecules of water, which they lose by heat.

250. *Strontic Nitrate*. — This salt, $\text{Sr}(\text{NO}_3)_2$, crystallizes in anhydrous octohedrons, which require for solution 5 parts of cold and about half their weight of boiling water. It is principally used in the composition of the well-known *red fire** of the pyrotechnist.

BARIUM.

251. *Its Properties, etc.* — This metal occurs abundantly as sulphate and carbonate, forming the *veinstone* in many lead-mines. Davy obtained it in the metallic state by means similar to those described in the case of lithium. It is malleable, melts below a red heat, decomposes water, and gradually oxidizes in the air.

252. *Baric Chloride*. — This valuable salt, $\text{BaCl}_2 \cdot \text{H}_2\text{O}$, is prepared by dissolving the native carbonate in muriatic acid, filtering the solution, and evaporating until a pellicle begins to form at the surface. The solution, on cooling, deposits crystals, which are flat four-sided tables, colorless and transparent.

253. *Baryta*. — *Baric monoxide*, or *baryta*, BaO , is best prepared by decomposing the crystallized nitrate by heat in a capacious porcelain crucible. Like strontia, it appears as a grayish spongy mass, fusible at a high degree of heat. When moistened with water it forms a hydrate, with great elevation of temperature.

* RED FIRE :	Grains.	GREEN FIRE :	Grains.
Dry strontic nitrate	800	Dry baric nitrate	450
Sulphur	225	Sulphur	150
Potassic chlorate	200	Potassic chlorate	100
Lamp-black	50	Lamp-black	25

The strontic or baric salt, the sulphur, and the lamp-black, must be finely powdered and intimately mixed, after which the potassic chlorate should be added in rather coarse powder, and mixed, without much rubbing, with the other ingredients. The red-fire composition has been known to ignite spontaneously.

254. *Baric Hydrate*. — This compound, BaH_2O_2 , is prepared on a large scale by decomposing a hot concentrated solution of baric chloride with a solution of caustic soda.

It is a white, soft powder, having a great attraction for carbonic acid, and soluble in 20 parts of cold and 2 parts of boiling water. In solution it is a valuable reagent; it is highly alkaline to test-paper, and instantly rendered turbid by the smallest trace of carbonic acid.

255. *Baric Nitrate*. — The nitrate $\text{Ba}(\text{NO}_3)_2$ is prepared in the same way as the chloride, nitric acid being substituted for muriatic. It crystallizes in transparent colorless octohedrons, which are anhydrous. They require for solution 8 parts of cold and 3 parts of boiling water.

256. *Baric Sulphate*. — This salt, BaSO_4 , is found native as *heavy spar* or *barytes*, often beautifully crystallized; its specific gravity is as high as 4.4 to 4.8. It is always produced when sulphuric acid or a soluble sulphate is mixed with a solution of a barium salt. It is not sensibly soluble in water or in dilute acids; even in nitric it is almost insoluble; hot oil of vitriol dissolves a little, but the greater part separates again on cooling. Baric sulphate is now produced artificially on a large scale; it is used as a substitute for white lead in the manufacture of oil-paints. The sulphate to be used for this purpose is precipitated from very dilute solutions; it is known in commerce as *blanc fixe*. Powdered native baric sulphate, being rather crystalline, has not sufficient *body*. For the production of sulphate, baric chloride is first prepared, which is dissolved in a large quantity of water, and then precipitated by dilute sulphuric acid.

LEAD.

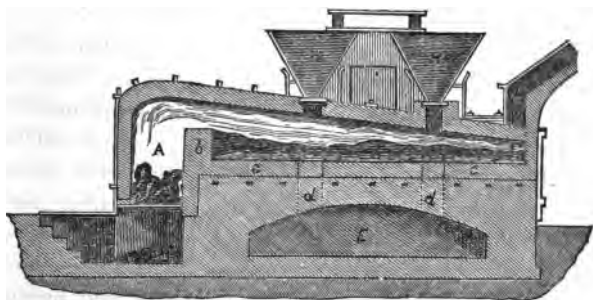
257. *Its Reduction, Properties, etc.* — This abundant and useful metal is altogether obtained from the native sul-

phide, or *galena*, no other lead-ore being found in large quantity. The reduction is effected in a reverberatory furnace,* into which the crushed lead-ore is introduced and roasted for some time at a dull red heat, by which much of the sulphide becomes changed by oxidation to sulphate. The contents of the furnace are then thoroughly mixed, and the temperature raised, when the sulphate and sulphide react upon each other, producing sulphurous anhydride and metallic lead : $\text{PbSO}_4 + \text{PbS} = \text{Pb}_2 + 2\text{SO}_2$.

Lead melts at 315.5° , or a little above, and boils and volatilizes at a white heat. By slow cooling it may be obtained in octohedral crystals. In moist air this metal becomes coated with a film of gray matter, thought to be the suboxide, Pb_2O ; exposed to the atmosphere in the melted state it rapidly absorbs oxygen. Dilute acids, with the exception of nitric acid, act but slowly upon lead.

* Such a furnace is represented in Figure 51. The ore is put into the hoppers *HH*, from which it falls into the chamber *C*, where it is

Fig. 51.



spread out on the bed *cc*. The fuel is burned on a hearth at *A*, separated from the ore by the bridge *b*. The heated gases rising from the burning fuel are *reverberated*, or reflected, by the arched roof of the furnace, and driven down upon the ore, and then pass off through the flue *f*. When the ore is sufficiently roasted, it is allowed to fall through openings, *dd*, into the chamber *E*. The ore is stirred from time to time, to expose fresh surfaces to the action of the air and the flame.

258. *Plumbic Chloride*. — This chloride, PbCl_2 , is prepared by precipitating a solution of plumbic nitrate or acetate with muriatic acid or common salt. It separates as a heavy white crystalline precipitate, which dissolves in about 33 parts of boiling water, and separates again, on cooling, in needle-shaped crystals.

259. *Plumbic Iodide*. — The iodide, PbI_2 , is precipitated, on mixing plumbic nitrate or acetate with potassic iodide, as a bright-yellow powder, which dissolves in boiling water, and crystallizes therefrom in beautiful yellow iridescent spangles.

260. *Plumbic Oxides*. — The *monoxide*, PbO , called *litharge* or *massicot*, is the product of the direct oxidation of the metal. It is most conveniently prepared by heating the carbonate to dull redness; common *litharge* is impure monoxide which has undergone fusion. It has a delicate straw-yellow color, is very heavy, and slightly soluble in water, giving an alkaline liquid. It is soluble in potash, and crystallizes from the solution in rhombic prisms. At a red heat it melts, and tends to crystallize on cooling. In the melted state it attacks and rapidly dissolves silicious matter, often penetrating an earthen crucible in a few minutes. It is easily reduced when heated with organic substances of any kind containing carbon or hydrogen. It forms a large class of salts, which are colorless if the acid itself is not colored.

Triplumbic tetroxide, or *red lead*, is not of very constant composition, but generally contains Pb_3O_4 or $2\text{PbO} \cdot \text{PbO}_2$. It is prepared by exposing the monoxide which has not been fused for a long time to the air, at a very faint red heat. It is a brilliant red and extremely heavy powder, decomposed, with evolution of oxygen, by a strong heat, and converted into a mixture of monoxide and dioxide by acids. It is used as a cheap substitute for vermilion.

The *dioxide*, PbO_2 , often called *puce* or *brown lead-oxide*, is

obtained by digesting red lead in dilute nitric acid, whereby plumbic nitrate is dissolved out, and insoluble dioxide left behind in the form of a deep-brown powder.

261. *Plumbic Nitrate*. — The salt, $\text{Pb}(\text{NO}_3)_2$, may be obtained by dissolving the carbonate in nitric acid, or by acting directly upon the metal by the same agent with the aid of heat; it is, as already noticed, a by-product in the preparation of the dioxide. It crystallizes in anhydrous octohedrons, which are usually milk-white and opaque.

262. *Plumbic Carbonate (White Lead)*. — This salt, PbCO_3 , is sometimes found beautifully crystallized in long white needles, accompanying other metallic ores. It is much used in the arts as a paint. It may be obtained in the pure state by precipitating a cold solution of the nitrate with an alkaline carbonate, when it falls down as a white powder. For preparing the salt in quantity, two plans are employed: the one similar in principle to that described for the pure salt, and the other known as the *Dutch method*. In this process thin sheets of lead are rolled into a coil, and each coil is placed in an earthen pot containing a small quantity of crude vinegar, which, however, does not come in contact with the lead. Several hundred of these jars and coils are packed on a floor in a bed of stable manure or spent tan-bark, and then covered with boards, while a second layer of pots similarly charged is placed above, and this is continued until the building is filled. After remaining thus for several weeks, the coils are taken out, when the greater part of the lead is found to be converted into white carbonate. It appears that plumbic acetate is first formed, and that the acetic acid is gradually driven out from its combination by the carbonic acid evolved from the putrefying organic matter, and is thus enabled to unite with another portion of the lead lying underneath that which was first attacked.

A preference is still given to the product of this old

mode of manufacture, on account of its superiority of opacity, or *body*, over that obtained by precipitation. Commercial white lead, however prepared, always contains a certain proportion of hydrate. It is sometimes adulterated with baric sulphate.

263. *Lead Water-Pipes, etc.* — The surface of lead remains bright in dry air, but it soon becomes tarnished in moist air, owing to the formation of a film of oxide; and this oxidation proceeds rapidly in presence of a small quantity of weak acid, such as carbonic or acetic. In pure water freed from air, lead also preserves its lustre; but if air be present, plumbic oxide is formed, and as this dissolves slowly in the water, a fresh portion of metal is exposed for oxidation. This solvent action of water upon lead is a matter of much importance, owing to the common use of lead water-pipes, and the peculiarly poisonous action of lead compounds upon the system when taken even in minute quantities for a length of time. The small quantity of certain salts contained in all spring and river waters exerts an important influence on the action of lead. Thus waters containing nitrates or chlorides are liable to contamination with lead, while those *hard* waters containing sulphates or carbonates may generally be brought into contact with lead without danger, as a thin deposit of sulphate or carbonate is formed, which preserves the metal from further action. If the water contains much free carbonic acid, it should not be allowed to come into contact with lead, as the carbonate dissolves in water containing this substance. The presence of lead in water may easily be demonstrated by acidulating the water, passing a current of hydric sulphide (sulphuretted hydrogen) through a deep column of the liquid, and noticing whether it becomes tinged of a brown color, from the formation of plumbic sulphide.

Lead pipes lined with tin have been recommended for

water-pipes ; but if the lining is not absolutely perfect, they are more dangerous than ordinary lead pipes. If, from defective soldering, or cracks, or breaks in the lining, or from corrosive action, the water comes in contact with the lead, a galvanic action begins, and the lead is more rapidly oxidized than it would be if not joined with the tin.

There is the same danger in the use of the metallic double-lined ice-pitchers. The lining is often made of dissimilar metals, and the parts are joined by a solder containing lead. The thin film of silver is soon worn off upon the interior ; galvanic action then promotes corrosive action, and the water becomes poisonous.

On the whole, the best way of protecting lead pipes from oxidation is by coating them with sulphide of lead, which is insoluble in water. This can be done by dissolving one pound of potassic sulphide (sulphide of potassium) in two gallons of water, and letting the solution remain in the pipe twelve hours, or until the whole inside is thoroughly blackened. This preventive process is not perfect, but it is very nearly so.

264. *The Metals of the Alkaline Earths.* — The three metals calcium, strontium, and barium, are intimately related, and constitute a well-defined family. They have less affinity for oxygen than the alkaline metals, but they readily decompose water. Their hydrates are less alkaline than those of the alkaline metals, are nearly insoluble in water, and can be decomposed by heat. Each metal forms two oxides, one of which is a strong base. Their compounds have the same gradation of properties already noticed in preceding groups of elements ; the compounds of calcium always being at one end of the scale, and those of barium at the other.

The compounds of lead are isomorphous with those of calcium, strontium, and barium, which they also resemble more or less closely in their chemical behavior.

GLASS, PORCELAIN, AND EARTHENWARE.

265. *Glass*. — Glass is a mixture of various insoluble silicates with excess of silica, altogether destitute of crystalline structure.

Two principal varieties of glass are met with in commerce : (1) glass composed of silica, alkali, and lime ; and (2) glass containing a large proportion of plumbic silicate. *Crown* and *plate glass* belong to the former division ; *flint glass*, and the material of artificial gems, to the latter. The lead promotes fusibility, and confers also density and lustre. Common green bottle-glass contains no lead, but much iron, derived from the impure materials. The principle of the glass manufacture is very simple. Silica, in the shape of sand, is heated with potassic or sodic carbonate, and slaked calcic or plumbic oxide ; at a high temperature fusion and combination occur, and the carbonic acid is expelled. Glauber's salt mixed with charcoal is sometimes substituted for soda. When the melted mass has become perfectly clear and free from air-bubbles, it is left to cool until it assumes the peculiar tenacious condition proper for working.

The fusion is conducted in large crucibles of refractory fire-clay, which in the case of lead-glass are covered by a dome at the top, and have an opening at the side, by which the materials are introduced, and the melted glass withdrawn. Great care is exercised in the choice of the sand, which must be quite white and free from iron oxide. Red lead (260), one of the higher oxides, is preferred to litharge, although immediately reduced to monoxide by the heat ; the liberated oxygen serving to destroy any combustible matter that might accidentally find its way into the crucible, and stain the glass by reducing a portion of the lead. Potash gives a better glass than soda, although

the latter is very generally employed, from its lower price. A certain proportion of broken and waste glass of the same kind is always added to the other materials.

In *blowing* glass, the workman first collects a proper quantity of soft pasty glass at the end of his *blowpipe*, an iron tube five or six feet in length, with a mouthpiece of wood; he then begins blowing, by which the lump is expanded into a kind of flask, the form of which is modified by the position in which it is held, and the velocity of rotation continually given to the iron tube. If an open-mouthed vessel is to be made, an iron rod called a *pontil* or *puntil*, is dipped into the glass-pot and applied to the bottom of the flask, to which it thus serves as a handle, the blowpipe being removed by the application of a cold iron to the neck. The vessel is then reheated at a hole left for the purpose in the wall of the furnace, and the aperture enlarged, and the vessel otherwise altered in figure by the aid of a few simple tools, until completed. It is then detached, and carried to the annealing oven (17), where it undergoes slow and gradual cooling during many hours. *Plate* glass is cast upon a flat metal table, and, after very careful annealing, is ground true and polished by suitable machinery. Tubes are made by rapidly drawing out a hollow cylinder.

Specimens of the two chief varieties of glass gave the following results on analysis:—

Bohemian plate glass (excellent).*		English flint glass.†	
Silica	60.0	Silica	51.93
Potassic oxide	25.0	Potassic oxide	13.77
Lime	12.5	Plumbic oxide	33.28
	<hr/> 97.5		<hr/> 98.98

Different colors are often communicated to glass by metallic oxides. Thus, maganic oxide gives violet or ame-

* Mitscherlich.

† Faraday.

thysat.; cupric oxide, green; ferrous oxide, dull green,* etc. These are either added to the melted contents of the glass-pot, in which they dissolve, or applied in a particular manner to the surface of the plate or other object, which is then reheated until the coloring matter is fused. The latter process is employed in *enamelling* and *glass-painting*. An opaque white appearance is given by oxide of tin; the enamel of watch-faces is thus prepared.

When silica is melted with twice its weight of potassic or sodic carbonate, and the product treated with water, the greater part dissolves, yielding a solution from which acids precipitate gelatinous silica. This is the *soluble glass* of Professor Fuchs; its solution has been used for rendering muslin and other fabrics of cotton or linen less combustible, for making artificial stone, and for preserving natural stone from decay.

266. *Porcelain*.—The plasticity of natural clays, and their hardening when exposed to heat, are properties which were known in very early times. There are few branches of industry of higher antiquity than that exercised by the potter.

True porcelain is distinguished from earthenware by very obvious characters. In porcelain the *body* of the ware is very compact and translucent, and breaks with a conchoidal fracture, the result of a partial fusion. The *glaze*, too, applied for giving a perfectly smooth surface,

* Advantage is taken of this in the preparation of colorless glass, for as it is difficult to obtain materials perfectly free from iron, which imparts a green color, a small quantity of black oxide of manganese is added to the mixture, and the violet color thus produced neutralizes the green, and a nearly colorless glass is the result.

The colors of precious stones are imitated by adding certain oxides to a brilliant lead-glass called *paste*; thus the blue of the sapphire is given by a small quantity of cobaltic oxide, while cuprous oxide imparts a ruby-red color, and ferric oxide a yellow color resembling *topaz*.

adheres closely, and, in fact, blends with the substance of the body. In earthenware, on the contrary, the fracture is open and earthy, and the glaze can be detached more or less readily. The compact and partly glossy character of porcelain is the result of the admixture with the clay of a small portion of some substance which is fusible at the temperature to which the ware is exposed when baked or *fired*, and being absorbed by the more infusible portion, binds the whole into a solid mass on cooling; such substances are found in felspar, and in a small admixture of calcic or alkaline silicate. The clay employed in porcelain making is always directly derived from decomposed felspar, none of the clays of the secondary strata being pure enough for the purpose; it must be white and free from ferric oxide. To diminish the contraction which this substance undergoes in the fire, a quantity of finely divided silica, carefully prepared by crushing and grinding calcined flints, is added, together with a proper proportion of felspar or other fusible material, also reduced to impalpable powder. The utmost pains are taken to effect perfect uniformity of mixture, and to avoid the introduction of particles of grit, or other foreign bodies. The ware itself is fashioned either on the potter's wheel, — a kind of vertical lathe, — or in moulds of plaster of Paris, and is dried first in the air, afterwards by artificial heat, and at length completely hardened by exposure to the temperature of ignition. The porous *biscuit* is now fit to receive its *glaze*, which may be either ground felspar, or a mixture of gypsum, silica, and a little porcelain clay, diffused through water. The piece is dipped for a moment into this mixture, and withdrawn; the water sinks into its substance, and the powder remains evenly spread upon its surface; it is once more dried, and, lastly, fired at an exceedingly high temperature.

The porcelain-furnace is a circular structure of masonry,

having several fireplaces, and surmounted by a lofty dome. Dry wood or coal is consumed as fuel, and its flame directed into the interior, and made to circulate around and among the earthen cases, or *seggars*, in which the articles to be fired are packed. Many hours are required for this operation, which must be very carefully managed. After the lapse of several days, when the furnace has completely cooled, the contents are removed in a finished state, so far as regards the ware.

The ornamental part, consisting of gilding and painting in enamel, has yet to be executed ; after which the pieces are again heated, in order to flux the colors. The operation has sometimes to be repeated more than once.

The manufacture of porcelain in Europe is of modern origin. The Chinese have possessed the art from the commencement of the seventh century, and their ware is, in some respects, altogether unequalled. The materials employed by them are known to be *kaolin*, or decomposed felspar ; *petuntze*, or quartz reduced to fine powder ; and the ashes of fern, which contain potassic carbonate.

267. *Stoneware*. — This is a coarse kind of porcelain, made from clay containing ferric oxide and a little lime, to which it owes its partial fusibility. The glazing is performed by throwing common salt into the heated furnace ; this is volatilized, and decomposed by the joint agency of the silica of the ware and of the vapor of water always present ; muriatic acid and soda are produced, the latter forming a silicate, which fuses over the surface of the ware, and gives a thin but excellent glaze.

268. *Earthenware*. — The finest kind of earthenware is made from a white secondary clay, mixed with a considerable quantity of silica. The articles are thoroughly dried and fired ; after which they are dipped into a readily fusible glaze mixture, of which plumbic oxide is usually an important ingredient, and, when dry, reheated till the glaze

is fused. The whole process is much easier than the making of porcelain, and demands less care. The ornamental designs in blue and other colors, so common upon plates and household articles, are printed upon paper in enamel pigment mixed with oil, and transferred, while still wet, to the unglazed ware. When the ink becomes dry, the paper is washed off, and the glazing completed.

Crucibles, when of good quality, are very valuable to the practical chemist. They are made of clay free from lime, mixed with sand or ground ware of the same description. The Hessian and Cornish crucibles are among the best. Sometimes a mixture of plumbago and clay is employed for the same purpose; and powdered coke has been also used with the earth. Such crucibles bear rapid changes of temperature with impunity.

MAGNESIUM GROUP OF METALS.

MAGNESIUM.

269. *Its Preparation.* — Magnesium occurs in the mineral kingdom as hydrate, carbonate, borate, phosphate, sulphate, and nitrate, sometimes in the solid state, sometimes dissolved in mineral waters. *Magnesian limestone*, or *dolomite*, which forms entire mountain masses, is a carbonate of magnesium and calcium. Magnesium also occurs as silicate, combined with other silicates, in a variety of minerals, as steatite, hornblende, augite, talc, etc.; also as aluminate in spinelle and zeilanite. It likewise occurs in the bodies of plants and animals, chiefly as carbonate and phosphate, and in combination with organic acids.

Metallic magnesium is prepared by reducing magnesian chloride, or the double chloride of magnesium and sodium or potassium, with metallic sodium. The double chloride is prepared by dissolving magnesian carbonate in muriatic

acid, adding an equivalent quantity of sodic or potassic chloride, evaporating to dryness, and fusing the residue. This product, heated with sodium in a wrought-iron crucible, yields metallic magnesium, containing certain impurities, from which it may be freed by distillation. This process is now carried out on the manufacturing scale, and the magnesium is drawn out into wire or formed into ribbon for burning.

270. *Its Properties.* — Magnesium is a brilliant metal, almost as white as silver, somewhat more brittle at common temperatures, but malleable at a heat a little below redness. Its specific gravity is 1.74. It melts at a red heat, and volatilizes at nearly the same temperature as zinc. It retains its lustre in dry air, but in moist air it becomes covered with a crust of magnesia.

Magnesium in the form of wire or ribbon takes fire at a red heat, burning with a dazzling bluish-white light. The flame of a candle or spirit-lamp is sufficient to inflame it, but to insure continuous combustion the metal must be kept in contact with the flame. For this purpose lamps are constructed, provided with clock-work for pushing the ribbon into the flame.

The magnesium flame produces a continuous spectrum, containing a very large proportion of the more refrangible rays; hence it is well adapted for photography, and has, indeed, been used for taking photographs, in the absence of the sun, or in places where sunlight cannot penetrate, as in caves or subterranean rooms.

271. *Magnesium Oxide or Magnesia.* — This oxide, MgO , is easily prepared by exposing the *magnesia alba* of pharmacy, which is a hydrocarbonate, to a full red heat in an earthen or platinum crucible. It forms a soft, white powder, which slowly attracts moisture and carbonic acid from the air, and unites quietly with water to a hydrate which possesses a feeble degree of solubility, requiring about

5,000 parts of water at 15.5° and 36,000 parts at 100° . The alkalinity of magnesia can only be observed by placing a small portion in a moistened state upon test-paper; it neutralizes acids, however, in the most complete manner. It is infusible.

272. *Magnesian Sulphate (Epsom Salt)*. — This salt, $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$, occurs in sea-water, and in many mineral springs, and is now manufactured in large quantities by acting on magnesian limestone with dilute sulphuric acid, and separating the magnesian sulphate from the greater part of the slightly soluble calcic sulphate by filtration. The crystals are derived from a right rhombic prism; they are soluble in an equal weight of water at 15.5° , and in a still smaller quantity at 100° . The salt has a nauseous bitter taste, and is used to some extent in medicine.

273. *Magnesian Carbonate*. — The *neutral* salt, MgCO_3 , occurs native in rhombohedral crystals, embedded in talc slate; a soft earthy variety is sometimes met with.

Magnesia alba, although often called magnesian carbonate, is in reality a compound of carbonate with hydrate. It is much used in medicine.

274. *Magnesian Silicates*. — The following are some of the natural compounds belonging to this class: (1) *chrysolite*, Mg_2SiO_4 , a crystallized mineral sometimes employed for ornamental purposes; (2) *meerschaum*, $2\text{SiO}_3 \cdot \text{MgSiO}_3$, a soft mineral from which pipe-bowls are made; (3) *talc*, $4\text{SiO}_3 \cdot \text{MgSiO}_2$ (called *steatite* when massive), is a soft, white, transparent or translucent mineral; (4) *soapstone*, also called *steatite*, a silicate of magnesium and aluminium of somewhat variable composition; (5) *serpentine*, a combination of silicate and hydrate of magnesium. *Augite* and *hornblende* are essentially double salts of silicic acid, magnesia, and lime, in which the magnesia is more or less replaced by its isomorphous substitute, ferrous oxide.

ZINC.

275. *Its Ores, Preparation, and Properties.* — Zinc is a somewhat abundant metal ; it is found in the state of carbonate, silicate, and sulphide, associated with lead-ores in many districts, both in Britain and on the Continent. Large supplies are obtained from Silesia, and from the neighborhood of Aachen. The native carbonate, or *calamine*, is the most valuable of the zinc ores, and is preferred for the extraction of the metal. It is first roasted to expel water and carbonic acid, then mixed with fragments of coke or charcoal, and distilled at a full red heat in a large earthen retort ; carbonic oxide escapes, while the reduced metal volatilizes and is condensed, generally mixed with minute quantities of arsenic.

Zinc is a bluish-white metal, which slowly tarnishes in the air ; it has a lamellar, crystalline structure, a density varying from 6.8 to 7.2, and is, under ordinary circumstances, brittle. Between 120° and 150° it is, on the contrary, malleable, and may be rolled or hammered without danger of fracture ; and, what is very remarkable, after such treatment, it retains its malleability when cold ; the sheet-zinc of commerce is thus made. At 210° it is so brittle that it may be reduced to powder. At 412° it melts ; at a bright red heat it boils and volatilizes, and, if air be admitted, burns with a splendid greenish light, generating the oxide. Dilute acids dissolve zinc very readily. It is much used for preparing hydrogen-gas.

Zinc is not acted upon by moist or dry air, and hence it is largely used in the form of sheets, and is employed as a protecting covering for iron. The sheets of iron are plunged into melted zinc, covered with sal-ammoniac, which keeps the surface of the zinc free from oxide, and allows the two metals to unite. Iron thus coated with zinc is said to be *galvanized*.

276. *Zinc Chloride*. — The chloride, ZnCl_2 , may be prepared by heating metallic zinc in chlorine, or, more easily, by dissolving zinc in muriatic acid. It is a nearly white, translucent, fusible substance, very soluble in water and alcohol, and very deliquescent. A strong solution of it is sometimes used as a bath for obtaining a graduated heat above 100° . It unites with sal-ammoniac and potassic chloride to form double salts. The former of these, made by dissolving zinc in muriatic acid, and then adding an equivalent quantity of sal-ammoniac, is very useful in tinning and soft-soldering copper and iron.

277. *Zinc Oxide*. — ZnO is a strong base, forming salts isomorphous with the magnesium salts. It is prepared either by burning zinc in atmospheric air, or by heating the carbonate to redness. It is a white, tasteless powder, insoluble in water, but freely dissolved by acids. When heated it is yellow, but turns white again on cooling. Under the name of *zinc-white*, it is coming into use as a substitute for white lead. To prepare zinc-white on a large scale, metallic zinc is volatilized in large earthen muffles, whence the vapor passes into a small receiver, where it comes in contact with a current of air, and is oxidized. The oxide thus formed passes immediately into a condensing chamber.

278. *Zinc Sulphate*. — This salt, $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$, is commonly called *white vitriol*. It is prepared either by dissolving the metal in dilute sulphuric acid, or, more economically, by roasting the native sulphide, or *blende*, which, by absorption of oxygen, becomes in great part converted into sulphate. Zinc sulphate has an astringent metallic taste, and is used in medicine as an emetic. The crystals dissolve in 2.5 parts of cold and in a much smaller quantity of hot water.

279. *Zinc Carbonate*. — This compound, ZnCO_3 , is found native. The white precipitate obtained by mixing solutions

of zinc and of alkaline carbonates is a combination of carbonate and hydrate. When heated to redness, it yields pure zincic oxide.

280. *Zincic Sulphide*. — ZnS occurs native, as *blende*, in regular tetrahedrons, dodecahedrons, and other monometric forms, and of various colors, from white or yellow to brown or black, according to its degree of purity ; it is a valuable ore of zinc.

CADMIUM.

281. *Its Properties, &c.* — This metal was discovered in 1817 by Stromeyer, and by Hermann. It accompanies the ores of zinc, especially those occurring in Silesia, and, being more volatile than that substance, rises first in vapor when the calamine is subjected to distillation with charcoal. Cadmium resembles tin in color, but is somewhat harder ; it is very malleable, has a density of 8.7, melts below 260° , and is nearly as volatile as mercury. It tarnishes but little in the air, but, when strongly heated, burns. Dilute sulphuric and muriatic acids act but little on this metal in the cold ; nitric acid is its best solvent.

The observed vapor density of cadmium is 3.94 compared with air as unity, or 56.3 compared with hydrogen, which latter number does not differ greatly from the half of 112, the atomic weight of the metal ; hence it appears that the *atom* of cadmium in the state of vapor occupies twice the space of an atom of hydrogen.

282. *Its Compounds*. — *Cadmic oxide*, CdO , is infusible ; it dissolves in acids, producing a series of colorless salts ; it attracts carbonic acid from the air, and turns white.

Cadmic sulphate, $\text{CdSO}_4 \cdot 4\text{H}_2\text{O}$, may be obtained by dissolving the oxide or carbonate in dilute sulphuric acid ; it is very soluble in water, and forms double salts with the sulphates of potassium and ammonium. Similar compounds are formed by magnesium and zinc.

Cadmic chloride, CdCl_2 , is a very soluble salt, crystallizing in small four-sided prisms.

Cadmic sulphide, CdS , is a very characteristic compound, of a bright yellow color, forming microscopic crystals, fusible at a high temperature. It is obtained by passing hydric sulphide through a solution of the sulphate, nitrate, or chloride. This compound is a pigment of great beauty and permanence. It occurs native as *greenockite*.

283. *Magnesium Group*. — The elements magnesium, zinc, and cadmium, constitute a third group of metals. They differ from the metals of the preceding group in forming but one oxide and sulphide. They resemble each other in their volatility, as well as in their chemical relations. The order of progression in this group is from magnesium to cadmium, zinc and its compounds always occupying an intermediate position.

The specific gravity of Mg is 1.75, of Zn 7.1, of Cd 8.6; the atomic weight of Mg 24, of Zn 65, and of Cd 112. Magnesium is volatilized at a bright red heat, cadmium at a low redness, and zinc at an intermediate temperature.

COPPER GROUP OF METALS.

COPPER.

284. *Its Ores, Properties, etc.* — Copper has been known from very early times, as it occurs native in the metallic state, and is moreover easily reduced from its ores. Metallic copper is found in enormous quantity near Lake Superior, in North America, and other localities. The following ores are the most important: (1) a compound of copper, sulphur, and iron, known as *copper pyrites*, $\text{Cu}_2\text{S} + \text{Fe}_2\text{S}_3$; (2) the *cuprous sulphide*, Cu_2S ; (3) the *carbonate* or *malachite*; and (4) the *red* or *cuprous oxide*, Cu_2O . Copper is obtained on a large scale from the carbonate or oxide, by

réducing these ores, together with carbon and some silica, in a blast-furnace.

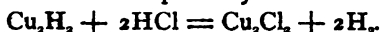
Metallic copper has a peculiar deep-red color, which is best seen when a ray of light is several times reflected from a bright surface of the metal. It has a specific gravity of 8.96, and is very malleable, ductile, and tenacious; it melts at a red heat, and is slightly volatile at a white heat, giving a green tint to a flame of hydrogen gas which is passed over it; and it is one of the best conductors of heat and electricity. It does not oxidize, either in pure dry or moist air, at ordinary temperatures; but if heated to redness in the air, it is soon converted into cupric oxide.

Dilute sulphuric and muriatic acids scarcely act upon copper; boiling oil of vitriol attacks it, with evolution of sulphurous anhydride; nitric acid, even dilute, dissolves it readily, with evolution of nitric oxide.

Copper is a dyad metal, its most stable compounds, the *cupric* compounds, containing 1 atom of the metal combined with 2 atoms of a univalent, or 1 atom of a bivalent negative radical; as, $\text{Cu}''\text{Cl}_2$, $\text{Cu}''\text{O}$, $\text{Cu}''(\text{NO}_3)_2$, $\text{Cu}''\text{SO}_4$, etc. Some of these, however, are capable of taking up another atom of copper, and forming the *cuprous* compounds, in which the copper is apparently univalent. Thus we have Cl-Cu-Cu-Cl , or Cu_2Cl_2 , *cuprous chloride*, etc. These compounds are very unstable, being easily converted into cupric compounds by oxidizing agents.

285. *Chlorides*. — *Cupric chloride*, CuCl_2 , is most easily prepared by dissolving cupric oxide in muriatic acid. It forms green crystals, $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$, very soluble in water and in alcohol; it colors the flame of the latter green. When gently heated it parts with its water of crystallization and becomes yellowish-brown; at a high temperature it loses half its chlorine and becomes converted into *cuprous chloride*. The latter is a white fusible substance, but little soluble in water, and prone to oxidation.

286. *Cuprous Hydride*. — When a solution of cupric sulphate is heated to about 70° , with hypophosphorous acid, this compound, Cu_2H_2 , is deposited as a yellow precipitate which soon turns red-brown. It gives off hydrogen when heated, takes fire in chlorine gas, and is converted by muriatic acid into cuprous chloride, with evolution of a double quantity of hydrogen, the acid giving up its hydrogen as well as the cuprous hydride : —



This reaction affords a remarkable instance of the union of two atoms of the same element to form a molecule.

287. *Copper Oxides*. — Two oxides of copper are known, corresponding to the chlorides.

Cupric oxide (black oxide of copper), CuO , is a heavy dark-brown or black powder. It is soluble in acids, and forms a series of very important salts.

Cuprous oxide, Cu_2O (also called *red oxide* and *suboxide of copper*), often occurs native in beautiful transparent ruby-red crystals, and can be obtained in the same state by artificial means. It gives glass a rich red tint, while that given by the cupric oxide is green.

288. *Cupric Sulphate*. — This beautiful salt, $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$, commonly called *blue vitriol*, is prepared by dissolving cupric oxide in sulphuric acid, or, at less expense, by oxidizing the sulphide. It forms large blue crystals, soluble in four parts of cold and two parts of boiling water; when heated to 100° it readily loses four molecules of crystallization-water; but the fifth is expelled only at a low red heat. This salt is much used in calico printing, and in making *cupric arsenate (Scheele's green)*, and other paints.

289. *Cupric Nitrate*. — This salt, $\text{Cu}(\text{NO}_3)_2 \cdot 3\text{H}_2\text{O}$, is easily made by dissolving the metal in nitric acid; it forms deep-blue crystals, very soluble and deliquescent. It is highly corrosive.

290. *Cupric Carbonates*. — When sodic carbonate is

added in excess to a solution of cupric sulphate, the precipitate is at first pale-blue and flocculent, but by warming it becomes sandy, and assumes a green tint; in this state it contains $\text{CuCO}_3 \cdot \text{CuH}_2\text{O}_2$, with some water of crystallization. It is used as a pigment. The beautiful mineral *malachite* has a similar composition, but contains no water of crystallization. *Azurite*, not yet artificially imitated, occurs in large transparent crystals of the most intense blue; it contains $2\text{CuCO}_3 \cdot \text{CuH}_2\text{O}_2$. *Verditer*, made by decomposing cupric nitrate with chalk, is said, however, to have a somewhat similar composition.

291. *Ammoniacal Copper Compounds*. — The chlorides, sulphate, nitrate, and other salts of copper, unite with one or more molecules of ammonia, forming, for the most part, crystalline compounds of blue or green color, some of which may be viewed as salts of metallammoniums (220).

292. *Alloys of Copper*. — *Brass* consists of copper alloyed with from 28 to 34 per cent of zinc; the latter may be added directly to the melted copper, or granulated copper may be heated with calamine and charcoal-powder, as in the old process. *Gun-metal*, a most valuable alloy, consists of 90 parts copper and 10 tin. *Bell* and *speculum metal* contain a still larger proportion of tin; these are brittle, especially the last-named. A good *bronze* for statues is made of 91 parts copper, 2 parts tin, 6 parts zinc, and 1 part lead. The *brass* or *bronze* of the ancients is an alloy of copper with tin, often also containing lead, and sometimes zinc.

MERCURY.

293. *Its History, Preparation, etc.* — This very remarkable metal, sometimes called *quicksilver*, has been known from early times. It is of great importance in the arts and in medicine.

Metallic mercury is occasionally met with in globules disseminated through the native sulphide, which is the ordinary ore. This latter substance, sometimes called *cinnabar*, is found in considerable quantity in several localities, of which the most celebrated are Almaden in Spain, and Idria in Austria. Only recently it has been discovered in great abundance, and of remarkable purity, in California and Australia. The metal is obtained by heating the sulphide in an iron retort with lime or scraps of iron, or by roasting it in a furnace, and conducting the vapors into a large chamber, where the mercury is condensed, while the sulphurous acid is allowed to escape.

294. *Its Properties.* — Mercury has a nearly silver-white color, and a very high degree of lustre; it is liquid at all ordinary temperatures, and solidifies only when cooled to -40° . In this state it is soft and malleable. At 350° it boils, and yields a transparent, colorless vapor, of great density. The metal volatilizes, however, to a sensible extent, at all temperatures above 19° or 21° . The specific gravity of mercury at 15.5° is 13.59; that of frozen mercury is about 14.

Pure mercury is quite unalterable in the air at common temperatures, but when heated to near its boiling point it slowly absorbs oxygen, and becomes converted into a crystalline dark-red powder, which is the highest oxide. At a dull red heat this oxide is again decomposed into its constituents (118). Muriatic acid has little or no action on mercury, and the same may be said of sulphuric acid in a diluted state; when the latter is concentrated and boiling hot, it oxidizes the metal, converting it into mercuric sulphate, with evolution of sulphurous anhydride. Nitric acid, even dilute and in the cold, dissolves mercury freely, with evolution of nitric oxide.

The observed vapor-density of mercury referred to air as unity is 6.7; this referred to hydrogen is nearly 100;

that is to say, half the atomic weight of the metal; consequently the atom of mercury, like that of cadmium, occupies in the gaseous state twice the volume of an atom of hydrogen.

Mercury forms two series of compounds; namely, the *mercuric* compounds, in which it is bivalent, as $\text{Hg}^{\text{II}}\text{Cl}_2$, $\text{Hg}^{\text{II}}\text{O}$, $\text{Hg}^{\text{II}}\text{SO}_4$, etc., and the *mercurous* compounds, in which it is apparently univalent, as Hg_2Cl_2 , Hg_2O , etc. These compounds are analogous in constitution to the cupric and cuprous compounds; and the mercurous compounds, like the latter, are easily converted into mercuric compounds by the action of oxidizing agents, which remove one atom of mercury; but they are, on the whole, much more stable than the cuprous compounds.

295. *Chlorides.* — *Mercuric chloride*, $\text{Hg}^{\text{II}}\text{Cl}_2$, is commonly called *corrosive sublimate*. It is a white transparent crystalline substance of specific gravity 5.43; it melts at 265° , boils at 295° , and volatilizes somewhat more easily than calomel, even at ordinary temperatures.

It dissolves in 16 parts of cold and 3 parts of boiling water, and crystallizes from a hot solution in long white prisms. Alcohol and ether also dissolve it with facility; the latter even withdraws it from a watery solution.

Mercuric chloride forms insoluble compounds with many of the nitrogenized organic principles, as albumen, etc. It is perhaps to this property that its strong *antiseptic* properties are due. Animal and vegetable substances are preserved by it from decay, as in Kyan's method of preserving timber and cordage. Albumen is on this account an excellent antidote to corrosive sublimate in cases of poisoning.

Mercurous chloride, Hg_2Cl_2 , commonly called *calomel*, may be easily and well prepared by pouring a solution of mercurous nitrate into a large excess of dilute solution of common salt.

It is a heavy, white, insoluble, tasteless powder ; it rises in vapor at a temperature below redness, and is obtained by ordinary sublimation as a yellowish-white crystalline mass. It is insoluble in cold diluted nitric acid ; but boiling-hot strong nitric acid oxidizes and dissolves it. Its use in medicine is well known.

296. *Mercuric Iodide*. — This salt, $\text{Hg}^{\text{II}}\text{I}_2$, is formed when solution of potassic iodide is mixed with mercuric chloride, as a precipitate which is at first yellow, but in a few moments changes to a most brilliant scarlet, this color being retained on drying. It exhibits a very remarkable case of dimorphism (49), attended with difference of color, which is red or yellow, according to the figure assumed. Thus, when the iodide is suddenly exposed to a high temperature, it becomes bright yellow throughout, and yields a copious sublimate of minute but brilliant yellow crystals. If in this state it be touched by a hard body, it instantly becomes red, and the same change happens spontaneously after a certain lapse of time. On the other hand, by a very slow and careful heating, a sublimate of red crystals, having a totally different form, may be obtained, which are permanent. The same kind of change happens with the freshly precipitated iodide, the yellow crystals first formed breaking up in the course of a few seconds from the passage of the salt to the red modification.

297. *Oxides*. — *Mercuric oxide*, HgO , is commonly called *red oxide of mercury*, or *red precipitate*. It has a red color, varying somewhat with the mode of preparation.

It is slightly soluble in water, to which it gives an alkaline reaction and a metallic taste ; it is highly poisonous.

Mercurous oxide, Hg_2O (*suboxide*, or *gray oxide of mercury*), is a dark gray, nearly black, heavy powder, insoluble in water, slowly decomposed by the action of light into metallic mercury and red oxide. The preparations known in pharmacy by the names *blue pill*, *gray ointment*, *mercury*

with chalk, etc., often supposed to owe their efficacy to this substance, merely contain the finely divided metal.

298. *Nitrates*. — Nitric acid varies in its action upon mercury, according to the temperature. When cold and somewhat diluted, it forms only mercurous salts, and these are neutral or basic according as the acid or the metal happens to be in excess. When the nitric acid is concentrated and hot, the mercury is raised to its highest state of oxidation, and a mercuric salt is produced. Both classes of salts are apt to be decomposed by a large quantity of water, giving rise to insoluble or sparingly soluble basic compounds.

299. *Mercuric Sulphide*. — This substance, HgS , occurs native as *cinnabar*, a dull red mineral, which is the most important ore of mercury. Hydric sulphide passed in small quantity into a solution of mercuric nitrate or chloride, forms a white precipitate, which is a compound of mercuric sulphide with the salt itself. An excess of the gas converts the whole into sulphide, the color at the same time changing to black. When this black sulphide is sublimed, it becomes dark-red and crystalline, but undergoes no change of composition; it is then called *cinnabar* or *vermilion*, and is much used as a paint.

300. *Ammoniacal Mercury Compounds*. — By the action of ammonia and its salts on mercury compounds, a variety of substances are formed which may be regarded as salts of *mercurammoniums* (220); that is, of ammonium molecules in which the hydrogen is more or less replaced by mercury, in the proportion of 100 or 200 parts of mercury to 1 part of hydrogen, according as the compound is formed from a mercurous or a mercuric salt.

301. *Alloys of Mercury*. — Alloys of mercury with other metals are termed *amalgams*: mercury dissolves in this manner many of the metals, as gold, silver, tin, lead, etc. The combination sometimes takes place with considerable

violence, as in the case of potassium, in which light and heat are produced ; besides this, many of the amalgams crystallize after a while, becoming solid. The amalgam of tin used in silvering looking-glasses,* and those of silver and of copper, sometimes employed by dentists for filling teeth, are examples.

302. *The Copper Group.*—Copper and mercury are alike in some of their leading properties, and in the fact that they form two chlorides and two basic oxides of analogous composition. Nitric and sulphuric acids also act upon the two metals in the same way, the acid being partially deoxidized and the metal dissolved.

IRON AND ALUMINIUM GROUP OF METALS.

IRON.

303. *Its Diffusion, its Properties, etc.*—This is the most important of the metals. There are few substances to

* "In order to apply it to the glass, a sheet of tin-foil is spread evenly upon a smooth slab of stone, which forms the top of a table carefully levelled, and surrounded by a groove, for the reception of the superfluous mercury. Clean mercury is poured upon the tin-foil, and spread uniformly over it with a roll of flannel ; more mercury is then poured on till it forms a fluid layer of the thickness of about half a crown ; the surface is cleared of impurities by passing a linen cloth lightly over it ; the plate of glass is carefully dried, and its edge being made to dip below the surface of the mercury, is pushed forward cautiously ; all bubbles of air are thus excluded as it glides over and adheres to the surface of the amalgam. The plate is then covered with flannel, weights are placed upon the glass, and the stone is gently inclined so as to allow the excess of mercury to drain off ; at the end of twenty-four hours it is placed upon a wooden table, the inclination of which is increased from day to day until the mirror assumes a vertical position : in about a month it is sufficiently drained to allow the mirror to be framed." — MILLER.

which it yields in interest, when it is considered how intimately the knowledge of its properties and uses is connected with human civilization.

Metallic iron is of exceedingly rare occurrence. It has been found at Canaan, in Connecticut, forming a vein about two inches thick in mica-slate; but it invariably enters into the composition of those extraordinary stones known to fall from the air, called *meteorites*. Isolated masses of soft malleable iron also, of large dimensions, lie loose upon the surface of the earth in South America and elsewhere, and are presumed to have had a similar origin; in common with the undoubted meteorites they contain nickel. In an oxidized condition, the presence of iron may be said to be universal; it constitutes a great part of the common coloring matter of rocks and soils; it is contained in plants, and forms an essential component of the blood of the animal body. It is also very common in the state of bisulphide.

Pure iron has a white color and perfect lustre; it is extremely soft and tough, and has a specific gravity of 7.8. Its crystalline form is probably the cube, to judge from appearances now and then exhibited. In good bar-iron or wire, a distinct fibrous texture may always be observed when the metal has been attacked by rusting or by the application of an acid, and upon the perfection of this fibre much of its strength and value depends. Iron is the most tenacious of the metals, a wire .028 of an inch in diameter bearing a weight of 60 lbs. It is very difficult of fusion, and before becoming liquid passes through a soft or pasty condition. Pieces of iron pressed or hammered together in this state cohere permanently. This operation is termed *welding*, and is usually performed by sprinkling a little sand over the heated metal, which combines with the superficial film of oxide, forming a fusible silicate, which is subsequently forced out from between the pieces

of iron by the pressure applied ; clean surfaces of metal are thus presented to each other, and union takes place without difficulty.

Iron does not oxidize in dry air at common temperatures. Heated to redness, it becomes covered with a scaly coating of black oxide, and at a high white heat burns brilliantly, producing the same substance. In oxygen gas the combustion occurs with still greater ease. The finely divided spongy metal prepared by reducing the red oxide with hydrogen gas takes fire spontaneously in the air. Pure water, free from air and carbonic acid, does not tarnish a surface of polished iron ; but the combined action of free oxygen and moisture speedily leads to the production of *rust*, which is a hydrate of the sesquioxide. The rusting of iron is wonderfully promoted by the presence of a little acid vapor. At a red heat, iron decomposes water, evolving hydrogen, and passing into the black oxide. Dilute sulphuric and muriatic acids dissolve it freely, with separation of hydrogen. Iron is strongly magnetic up to a red heat, when it loses all traces of that remarkable property.

Iron is a tetrad, forming two classes of compounds, namely, the *ferrous* compounds, in which it is bivalent, as $\text{Fe}^{\text{II}}\text{Cl}_2$, $\text{Fe}^{\text{II}}\text{O}$, $\text{Fe}^{\text{II}}\text{SO}_4$, etc. ; and the *ferric* compounds, in which it is really quadrivalent, though apparently trivalent, as $\text{Cl}_3\text{Fe-FeCl}_3$, or Fe_2Cl_6 , *ferrous chloride*, etc.

304. *Chlorides*. — The *dichloride*, or *ferrous chloride*, FeCl_2 , is formed by dissolving iron in muriatic acid. The solution yields green crystals of the hydrated dichloride, $\text{FeCl}_2 \cdot 4\text{H}_2\text{O}$, which are very soluble and deliquescent, and rapidly oxidize in the air.

The *trichloride*, or *ferric chloride*, Fe_2Cl_6 , is usually prepared by dissolving ferric oxide in muriatic acid. The solution, evaporated to a sirupy consistence, deposits red hydrated crystals, which are very soluble in water and alcohol.

305. *Iodides*. — *Ferrous iodide*, FeI_2 , is an important medicinal preparation; it is easily made by digesting iodine with water and metallic iron. The solution is pale-green, and yields, on evaporation, crystals resembling those of the chloride, which rapidly oxidize on exposure to air. It is best preserved in solution in contact with excess of iron. *Ferric iodide*, Fe_2I_6 , is yellowish-red and soluble.

306. *Oxides*. — Three oxides of iron are known, namely, *ferrous oxide*, FeO , and *ferric oxide*, Fe_2O_3 , analogous to the chlorides, and an intermediate oxide, containing Fe_3O_4 , or $\text{FeO} \cdot \text{Fe}_2\text{O}_3$. A *trioxide*, FeO_3 , is supposed to exist in a class of salts called *ferrates*, but it has not been isolated.

Ferrous oxide, FeO , is a very powerful base, neutralizing acids, and isomorphous with magnesia, zincic oxide, etc. It is almost unknown in the separate state, from its extreme proneness to absorb oxygen and pass into ferric oxide. The soluble ferrous salts have commonly a delicate pale-green color and a nauseous metallic taste.

Ferric oxide, Fe_2O_3 , is a feeble base, isomorphous with alumina. It occurs native, most beautifully crystallized, as *specular iron ore*, in the Island of Elba, and elsewhere; also as red and brown *haematite*, the latter being a hydrate. It dissolves in acids with difficulty after strong ignition, forming a series of reddish salts, which have an acid reaction and an astringent taste. Ferric oxide is not acted upon by the magnet.

Ferroso-ferric oxide, $\text{Fe}_3\text{O}_4 = \text{FeO} \cdot \text{Fe}_2\text{O}_3$, also called *black iron oxide*, *magnetic oxide*, and *loadstone*, is a natural product, one of the most valuable of the iron ores, often found in regular octohedral crystals, which are magnetic. This oxide is the chief product of the oxidation of iron at a high temperature in the air and in aqueous vapor. It is incapable of forming definite salts.

307. *Ferrous Sulphate*. — This beautiful and important salt, $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$, commonly called *green vitriol*, or *cop-*

peras, may be obtained by dissolving iron in dilute sulphuric acid; it is generally prepared, however, and on a very large scale, by the slow oxidation of *iron pyrites*, FeS_2 . Heaps of this material are exposed for some time to the air; the salt produced is then dissolved out by water, and the solution made to crystallize. It forms large green crystals, which slowly effloresce and oxidize in the air; it is soluble in about twice its weight of cold water. It is largely used in the manufacture of black ink and of several black dyes.

308. *Nitrates*. — When dilute cold nitric acid is made to act to saturation upon ferrous sulphide, FeS , and the solution is evaporated in a vacuum, pale-green and very soluble crystals of *ferrous nitrate*, $\text{Fe}(\text{NO}_3)_2$, are obtained, which are unstable. *Ferric nitrate* is readily formed by pouring nitric acid, slightly diluted, upon iron; it is a deep-red liquid, apt to deposit an insoluble basic salt, and is used in dyeing.

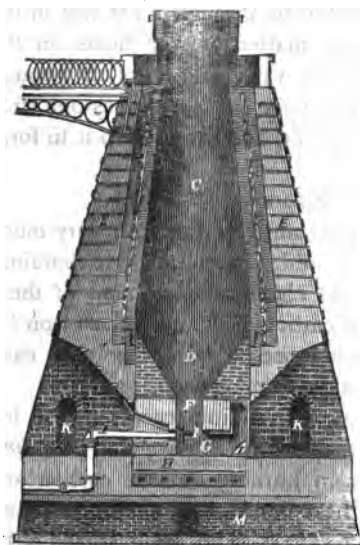
309. *Ferrous Carbonate*. — This substance, FeCO_3 , occurs in nature as *spathose iron ore*, or *iron spar*, associated with variable quantities of calcic and magnesian carbonates; also in the common *clay iron-stone*, from which nearly all the British iron is made. It is often found in mineral waters, being soluble in excess of carbonic acid; such waters are known by the rusty matter they deposit on exposure to the air. No *ferric carbonate* is known.

310. *Sulphides*. — There are several compounds of iron and sulphur, but only two are important. *Ferrous sulphide*, FeS , is a blackish brittle substance, attracted by the magnet, formed by heating together iron and sulphur. It is dissolved by dilute acids, with evolution of hydric sulphide gas. (135). *Ferric sulphide*, FeS_2 , or *iron pyrites*, is a natural product, occurring in rocks of all ages, and evidently formed in many cases by the gradual deoxidation of ferrous sulphate by organic matter. It has a brass-yellow color, is

very hard, not attracted by the magnet, and not acted upon by dilute acids. When it is exposed to heat sulphur is expelled, and an intermediate sulphide, Fe_3S_4 , analogous to the black oxide, is produced. This substance also occurs native, under the name of *magnetic pyrites*. Iron pyrites is now extensively employed for the manufacture of sulphuric acid. The mineral is roasted in a current of air, and the sulphurous acid formed is passed into the lead chambers; the residue consists of iron oxide, frequently containing copper enough to pay for extraction.

311. *Manufacture of Iron.* — The oldest method of manufacturing wrought-iron was to heat the ore in a blast-furnace with charcoal or coal, and to hammer out the spongy mass of iron thus obtained. This plan can only be economically followed on a small scale and with the purest ores, and has been superseded by a more complicated method, applica-

Fig. 52.



ble to all kinds of iron ore. The most important ore is an impure carbonate called *clay ironstone*. This is first *roasted* (that is, heated in contact with air) to drive off the carbonic acid, and reduce the iron to an oxide. It is next *smelted* in a *blast-furnace*. These furnaces (Figure 52) are usually about fifty feet high, and about fifteen feet in diameter in the widest part of the cavity *C D*. The lowest part, *F*, is called the *crucible*, or *hearth*. II

are the *tuyères*, or pipes through which air is forced by powerful bellows. *K*, *K*, and *M* are arched galleries for the convenience of workmen employed about the furnace. When working regularly, the furnace is charged from a door at the end of the gallery near the top, first with coal, and then with a mixture of roasted ore and limestone broken into small pieces. As the fuel burns away and the materials gradually sink, fresh supplies of fuel and of ore are added ; so that the furnace is kept filled with alternate layers of each.

The oxygen of the air from the bellows combines with the carbon of the fuel, forming carbonic oxide, CO , which rises through the porous mass, and, taking the oxygen from the ore, becomes converted into carbonic acid, CO_2 . The iron, mixed with the earthy matter of the ore, settles down into the hottest part of the furnace, where both are melted. The iron, being the heavier, sinks to the bottom, where it is drawn off at intervals through a *tap-hole* in the floor *H*. The lighter earthy matter, or *slag*, floats on the surface of the iron, like oil on water, and flows off through an opening above the *tymp-stone* *L*. The limestone aids in liquefying the earthy matter, and unites with it to form the slag.

At this stage the iron is *cast-iron*.

The properties and appearance of cast-iron vary much with the amount of carbon and silicon which it contains ; for cast-iron is not a definite chemical compound of these elements with iron. The carbon is found in cast-iron (1) as scales of graphite, giving rise to *mottled* or *gray* cast-iron ; and (2) in combination, forming *white* cast-iron.

In order to make *wrought-iron* from cast-iron, the latter must undergo the processes of *refining* and *puddling*. These consist essentially in burning out the carbon and silicon by exposing the heated metal to a current of air in a *reverberatory* furnace (257). The ore is stirred at in-

tervals, to expose fresh surfaces to the air and the flame. The melted cast-iron becomes first covered with a coat of oxide, and gradually thickens, so as to allow of its being rolled into large lumps or balls. During this process, the whole of the carbon escapes as carbonic oxide, and the silicon becomes oxidized to silica, which unites with the oxide of iron, and forms a fusible slag. Any phosphorus or sulphur contained in the iron is also oxidized in this process. The ball is then hammered, to give the metal coherence, and to squeeze out the liquid slag, and the mass is afterwards rolled into bars or plates.*

312. *Steel*. — Steel is formed when bars of wrought-iron are heated to redness for some time in contact with charcoal. The bar is then found to have become fine-grained instead of fibrous; the substance is more malleable and more easily fusible than the original bar-iron, and is found to contain carbon varying in amount from 1.3 to 1.7 per cent.† Steel has several important properties, especially the power of becoming very hard and elastic when quickly cooled, which fits it for the manufacture of edge-tools.

* To make the best iron, the bar is cut into a number of pieces, which are afterwards piled or bound together, again raised to a welding heat, and hammered or rolled into a single bar; and this process of *piling* or *fagoting* is sometimes twice or thrice repeated, the iron becoming greatly improved thereby.

† Some chemists have recently asserted that nitrogen is necessary for the production of steel, and have, in fact, attributed to its presence the peculiar properties of this material; others, again, have disputed this assertion, and believe that the transformation of iron into steel depends upon the assimilation of carbon only; experimentally, the question remains undecided.

Excellent steel is obtained by fusing gray cast-iron with tungstic oxide; the carbon of the iron reduces the tungstic oxide to tungsten, which forms with the iron an alloy possessing the properties of steel. The quantity of tungsten thus absorbed by the iron is very small, and some chemists ascribe the properties of the so-called *tungsten steel* to the general treatment rather than to the presence of tungsten.

These are, however, generally made of bar-steel, which has been previously fused and cast into ingots.

A new and very rapid mode of preparing cast-steel is that known as the *Bessemer process*. This process consists in burning out all the carbon and silicon in cast-iron, by passing a blast of atmospheric air through the molten metal, and then adding such a quantity of pure cast-iron to the wrought-iron thus prepared as is necessary to give carbon enough to convert the whole mass into steel. The melted steel is then at once cast into ingots. In this way six tons of cast-iron can, at one operation, be converted into steel in twenty minutes. The Bessemer steel is now largely manufactured for railway axles and rails, for boiler-plates and other purposes, for which it is much better fitted than wrought-iron, so that this process bids fair to revolutionize the old iron industry. It has already been put into practice on a large scale in England, France, Belgium, Sweden, and India.

The most remarkable property of steel is that of becoming exceedingly hard when quickly cooled. When heated to redness, and suddenly quenched in cold water, steel, in fact, becomes capable of scratching glass with facility; if reheated to redness, and once more left to cool slowly, it again becomes nearly as soft as ordinary iron; and between these two conditions any required degree of hardness may be attained. The articles, forged into shape, are first hardened in the manner described; they are then *tempered* (17) by exposure to a proper degree of annealing heat, which is often judged of by the color of the thin film of oxide which appears on the polished surface. Thus, a temperature of about 221° (430° F.), indicated by a faint straw color, gives the proper temper for razors; that for scissors, penknives, etc., ranges between 243° (470° F.) and 254° (490° F.), and is indicated by a full-yellow or brown tint. Swords and watch-springs require to be softer

and more elastic, and must be heated to 288° (550° F.) or 293° (560° F.), or until the surface becomes deep blue. Attention to these colors has now become of less importance, as metal baths are often substituted for the open fire in this operation.

NICKEL.

313. *Its Sources, Properties, etc.* — Nickel is found in tolerable abundance in some of the metal-bearing veins of the Saxon Mountains, in Westphalia, Hesse, Hungary, and Sweden, chiefly as arsenide, the *kupfernickel* of mineralogists, so called from its yellowish-red color. The word *nickel* is a term of detraction, having been applied by the old German miners to what was looked upon as a kind of false copper ore.

The artificial, or perhaps merely fused, product called *speiss*, is nearly the same substance, and may be employed as a source of the nickel salts. This metal is found in meteoric iron, as already mentioned (301).

Nickel is a white, malleable metal, having a density of 8.8 and a high melting-point. It is less easily oxidized than iron, since it is but little attacked by dilute acids. It is strongly magnetic, but loses this property when heated to 350° .

314. *Oxides.* — Nickel forms two oxides analogous to the two principal oxides of iron.

The *monoxide*, NiO , is an ashy-gray powder, freely soluble in acids, which it completely neutralizes, forming salts isomorphous with those of magnesium. Nickel salts, when hydrated, have usually a beautiful emerald-green color; in the anhydrous state they are yellow.

The *sesquioxide*, Ni_2O_3 , is a black insoluble substance, which is decomposed by heat, and evolves chlorine when treated with hot muriatic acid.

The chief use of nickel in the arts is in the preparation of a white alloy, sometimes called *German silver*, made by melting together 100 parts of copper, 60 of zinc, and 40 of nickel. This alloy is very malleable, and takes a high polish.

COBALT.

315. *Its Properties, etc.* — This substance bears, in many respects, a close resemblance to nickel, with which it is often associated in nature.

It is a white, brittle, very tenacious metal, having a specific gravity of 8.5, and a very high melting-point. It is unchanged in the air, and but feebly attacked by dilute muriatic and sulphuric acids. It is strongly magnetic.

Cobalt forms two classes of salts, analogous in composition to the ferrous and ferric salts; but the *cobaltic* salts are very unstable.

316. *Cobaltous Chloride.* — This compound, $\text{Co}^{\text{I}}\text{Cl}_2$, is easily prepared by dissolving the oxide in hydrochloric acid. In dilute solution it constitutes the well-known *blue sympathetic ink*. Characters written on paper with this liquid are invisible, from their paleness of color, until the salt has been rendered anhydrous by exposure to heat, when the letters appear blue. On laying it aside, moisture is absorbed, and the writing once more disappears.

317. *Oxides, etc.* — Cobalt forms two oxides analogous to those of nickel, with two or three of intermediate composition not very well defined. *Cobaltous oxide*, $\text{Co}^{\text{I}}\text{O}$, is a gray powder, very soluble in acids, and is a strong base, isomorphous with magnesia, affording salts of a fine red tint.

Cobaltic oxide, Co_2O_3 , is a black, insoluble, neutral powder, which dissolves in acids, yielding the cobaltic salts.

The substance called *smalt*, used as a pigment, consists

of glass colored by cobalt. The cobalt ore is roasted until nearly free from arsenic, and then fused with a mixture of potassic carbonate and quartz-sand, free from oxide of iron. Any nickel that may happen to be contained in the ore then subsides to the bottom of the crucible, as arsenide or *speiss*. The glass, when complete, is removed and poured into cold water, and is afterwards ground to powder. *Cobalt-ultramarine* is a fine blue color prepared by mixing 16 parts of freshly precipitated alumina with 2 parts of phosphate or arsenate of cobalt; this mixture is dried and slowly heated to redness. By daylight the color is pure blue, but by artificial light it is violet. A similar compound, of a fine green color, is formed by igniting zincic oxide with cobalt salts. *Zaffre* is the roasted cobalt ore mixed with silicious sand, and reduced to fine powder; it is used in enamel painting. A mixture in due proportions of the oxides of cobalt, manganese, and iron, is used for giving a fine black color to glass.

MANGANESE.

318. *Sources, Properties, etc.* — Manganese is tolerably abundant in nature in an oxidized state, entering into the composition of several interesting minerals. Traces of it are very frequently found in the ashes of plants. It has a reddish lustre like bismuth; it is very hard and brittle, with a specific gravity of 7.13. When powdered, it decomposes water, even at the lowest temperature. Dilute sulphuric acid dissolves it with great energy, evolving hydrogen.

319. *Oxides.* — Manganese forms four well-defined oxides:—

Manganous oxide	MnO
Manganoso-manganic oxide	Mn ₃ O ₄
Manganic oxide	Mn ₂ O ₃
Manganic dioxide or peroxide	MnO ₂

The first is a strong base, the third a weak base ; the second and fourth are neutral. The second may be regarded as a compound of the first and third, $\text{MnO} \cdot \text{Mn}_2\text{O}_3$. There are also several intermediate oxides, occurring as natural minerals or ores of manganese. Manganese likewise forms two series of oxygen salts, called *manganates* and *permanganates*, the composition of which may be illustrated by the potassium salts, viz. : —

Potassic manganate	K_2MnO_4
Potassic permanganate	$\text{K}_2\text{Mn}_2\text{O}_8$

The oxides, MnO_3 and Mn_2O_7 , corresponding to these salts, are not known.

Manganous oxide is a very powerful base, being isomorphous with magnesia and zincic oxide ; it dissolves quietly in dilute acids, neutralizing them completely and forming salts, which have often a beautiful pink color.

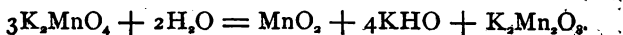
Manganic oxide occurs in nature as *braunite*, and in the state of hydrate as *manganite*. Its color is brown or black, according to its origin or mode of preparation. It is a feeble base, isomorphous with alumina. 5

Manganic dioxide, or *black oxide of manganese*, is the most common ore of manganese. It is found in many parts of Europe ; but the most productive mines are in Thuringia and Moravia. More than 18,000 tons are used annually in England in the manufacture of bleaching-powder.

320. *Manganous Sulphate*. — This is a beautiful rose-colored and very soluble salt, $\text{MnSO}_4 \cdot 7\text{H}_2\text{O}$. It is extensively used to produce a permanent brown dye, the cloth steeped in the solution being afterwards passed through a solution of bleaching-powder, by which the manganous oxide is changed to insoluble hydrate of the dioxide.

321. *Permanganates*. — When potassic manganate, free from any great excess of alkali, is put into a large quantity

of water, it is resolved into hydrated manganic dioxide which subsides, and *potassic permanganate*, $K_2Mn_2O_8$, which remains in solution, forming a deep-purple liquid :—



This effect is accelerated by heat. The changes of color accompanying this decomposition are very remarkable, and have procured for the manganate the name *chameleon mineral*; excess of alkali hinders the reaction in some measure, by conferring greater stability on the manganate. The crystals of potassic permanganate have a dark-purple color, and are not very soluble in cold water. The manganates and permanganates are decomposed by contact with organic matter. The green and red disinfecting agents known as *Condy's fluids* are alkaline manganates and permanganates.

Hydric permanganate, or *permanganic acid*, $H_2Mn_2O_8$, is obtained by dissolving potassic permanganate in hydric sulphate (H_2SO_4) diluted with one molecule of water, and distilling the solution at 60° – 70° . Permanganic acid then passes over in violet vapors, and condenses to a greenish-black liquid, which has a metallic lustre, absorbs moisture greedily from the air, and acts as a most powerful oxidizing agent, instantly setting fire to paper and to alcohol.

ALUMINIUM.

322. *Sources, Preparation, and Properties.*—This metal occurs very abundantly in nature in the state of silicate, as in felspar and its associated minerals; also in the various modifications of clay thence derived. It was first isolated by Wöhler, who obtained it as a gray powder by decomposing aluminic chloride with potassium; and H. Sainte-Claire Deville, by an improved process founded on the same principle, has succeeded in obtaining it in the com-

compact form and on the manufacturing scale. The process consists in decomposing the double chloride of aluminium and sodium, $\text{Al}_2\text{Cl}_6 \cdot 2\text{NaCl}$, by heating it with metallic sodium, fluor spar or cryolite being added as a flux. The reduction is effected in crucibles, or on the large scale in a reverberatory furnace. Sodium is used as the reducing agent in preference to potassium; first, because it is more easily prepared; and, secondly, because it has a lower atomic weight, and, consequently, a smaller quantity of it suffices to do the same amount of chemical work.

Aluminium is also prepared directly from cryolite by reduction with sodium; but the metal thus obtained is said to be more contaminated with iron and silicon than that prepared by Deville's process.

Aluminium is remarkable for its low specific gravity, which is 2.6; it is nearly as white as silver, and is capable of assuming a high polish. It is employed in the manufacture of delicate apparatus and ornamental articles. Some of the alloys of aluminium promise to become more generally applicable, more especially the alloy with copper, which is remarkable for being similar in appearance to gold; this alloy is found already in commerce under the name of *aluminium bronze*.

Aluminium forms only one class of compounds, in all of which it appears to be trivalent, one atom of the metal being equivalent to three atoms of hydrogen; thus the chloride is $\text{Al}'''\text{Cl}_3$, the oxide $\text{Al}'''\text{O}_3$, etc. Each of these compounds, however, contains two atoms of aluminium, and it may therefore be supposed that the aluminium is really tetradic, one unit of equivalency in each atom being neutralized by one unit in the other; thus the chloride is $\text{Cl}_3=\text{Al}-\text{Al}=\text{Cl}_3$.

323. *Aluminic Oxide (Alumina)*.—This substance, Al_2O_3 , is prepared by mixing a solution of alum with excess of ammonia, by which an extremely bulky, white gelatinous

precipitate of aluminic hydrate is thrown down. This is washed, dried, and ignited to whiteness. Thus obtained, alumina is a white, tasteless, coherent mass, very little acted upon by acids. It is fusible before the oxy-hydrogen blow-pipe. The mineral called *corundum*, of which the ruby and sapphire are transparent varieties, consists of nearly pure alumina in a crystallized state, with a little coloring oxide. *Emery*, used for polishing glass and metals, is a coarse variety of corundum. Alumina is a very feeble base, and its salts have often an acid reaction.

324. *Aluminic Hydrate*. — This hydrate, $\text{Al}_2\text{H}_2\text{O}_6$, has a very powerful attraction for organic matter, and when digested in solutions of vegetable dyes, combines with and carries down the coloring matter, which is thus removed entirely from the liquid if the alumina is in sufficient quantity. The pigments called *lakes* are compounds of this nature. The fibre of cotton impregnated with alumina acquires the same power of retaining coloring matters; hence the great use of aluminous salts as *mordants* to produce fast colors.

325. *Aluminates*. — The hydrogen in aluminic hydrate may be replaced by an equivalent quantity of various metals; such compounds are called *aluminates*. According to Frémy, a solution of alumina in potash slowly evaporated, out of contact with the air, deposits granular crystals of potassic aluminate, $\text{KAl}^{\text{III}}\text{O}_2$. Similar compounds occur native; thus *spinell* is an aluminate of magnesium, $\text{Mg}^{\text{II}}\text{Al}^{\text{III}}_2\text{O}_4$; *gahnite*, an aluminate of zinc, $\text{Zn}^{\text{II}}\text{Al}^{\text{III}}_2\text{O}_4$.

326. *Aluminic Sulphate*. — This salt, $\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$, is prepared by saturating dilute sulphuric acid with aluminic hydrate, and evaporating; or, on the large scale, by heating clay with sulphuric acid. It crystallizes in thin pearly plates, soluble in 2 parts of water; it has a sweet and astringent taste, and an acid reaction. Heated to redness, it is decomposed, leaving pure alumina.

327. *Alums*. — Aluminic sulphate combines with the sulphates of potassium, sodium, and ammonium, and the other alkali metals, forming double salts of great interest, called *alums*. Common alum, or *potash alum*, the source of all the preparations of alumina, contains $K_2Al(SO_4)_3 \cdot 24H_2O$. It may be prepared by dissolving the two sulphates together, and allowing the compound salt to crystallize, but it is usually obtained from the decomposition of a shale or clay containing iron pyrites, FeS_2 . This substance gradually undergoes oxidation when the shale is roasted (taking oxygen from the air), producing sulphuric acid, which unites with the alumina of the clay, and, on the addition of a potassic compound, alum crystallizes out in colorless, transparent octohedrons, which often exhibit the faces of the cube. It has a sweetish and astringent taste, reddens litmus-paper, and dissolves in 18 parts of water at 15.5° , and in its own weight of boiling water. Exposed to heat it is easily rendered anhydrous, and by a very high temperature it is decomposed. The crystals have little tendency to change in the air. Alum is largely used in the arts, in preparing skins, dyeing, etc. A mixture of dried alum and sugar, carbonized in an open pan, and then heated to redness in a glass flask, contact with air being avoided, furnishes the *pyrophorus of Homberg*, which ignites spontaneously on exposure to the atmosphere. The essential ingredient is probably finely divided potassic sulphide.

Soda alum, in which sodic sulphate replaces potassic sulphate, is much more soluble and difficult to crystallize than potash alum.

Ammonia alum, containing H_4N instead of K, very closely resembles common potassic alum, having the same figure, appearance, and constitution, and nearly the same degree of solubility. As the value of potassium salts is continually increasing, ammonia alum, which may be used

in dyeing with the same advantage as the potash alum, has almost entirely replaced the latter.*

328. *Aluminic Silicates*. — These enter into the composition of a number of crystallized minerals, of which felspar is the most abundant. *Granite, porphyry, trachyte*, and other ancient unstratified rocks, consist in great part of this mineral, which, under peculiar circumstances, by no means well understood, and particularly by the action of the carbonic acid of the air, suffers complete decomposition, becoming converted into a soft, friable mass of earthy matter. This is the origin of *clay*. The change itself is seen in great perfection in certain districts in Devonshire and Cornwall, England, the felspar of the fine white granite of those localities being often disintegrated to an extraordinary depth, and the rock altered to a substance resembling soft mortar. By washing, this finely divided matter is separated from the quartz and mica; and the milk-like liquid, being collected in tanks and suffered to stand, deposits the suspended clay, which is afterwards dried, first in the air and afterwards in a stove, and employed in the manufacture of porcelain. The composition assigned to unaltered felspar is AlKSi_3O_8 . The exact nature of the change by which felspar passes into porcelain clay is unknown, although it evidently consists in the abstraction of silica and alkali.

It is a common mistake to confound clay with alumina. All clays are essentially silicates of that base; they often vary a good deal in composition. Dilute acids exert little action on these compounds; but by boiling with oil of vitriol, alumina is dissolved out, and finely divided silica

* There is a *caesium alum*, $\text{Cs}_2\text{Al}_2(\text{SO}_4)_4 \cdot 24\text{H}_2\text{O}$, and there are *rubidium, thallium, and silver* alums having a precisely similar composition. There are also corresponding salts in which the *aluminium* is replaced by iron, chromium, and manganese. Thus we have *potassio-ferric sulphate*, $\text{K}_2\text{Fe}_2(\text{SO}_4)_4 \cdot 24\text{H}_2\text{O}$; *ammonio-chromic sulphate*, $\text{Cr}_2(\text{H}_4\text{N})_2(\text{SO}_4)_4 \cdot 24\text{H}_2\text{O}$, etc.

left behind. Clays containing an admixture of calcic carbonate are termed *marks*. These effervesce with acids.

CHROMIUM.

329. *Its Properties, etc.*—Chromium is found in the state of oxide, in combination with ferric oxide, in some abundance in the Shetland Islands, and elsewhere. As plumbic chromate it constitutes a very beautiful mineral, from which it was first obtained.

Metallic chromium is less fusible than platinum, and as hard as corundum. It is readily acted upon by dilute muriatic acid, less so by dilute sulphuric acid, and not at all by concentrated nitric acid.

Chromium forms a hexfluoride $\text{Cr}^{\text{VI}}\text{F}_6$, and a corresponding oxide $\text{Cr}^{\text{VI}}\text{O}_3$, analogous to sulphuric anhydride; also, an acid, H_2CrO_4 , analogous to sulphuric acid, with corresponding salts, the chromates, which are isomorphous with the sulphates. In its other compounds, it resembles iron, forming the *chromic* compounds Cr_2Cl_6 , Cr_2O_3 , etc., in which it is apparently trivalent but really quadrivalent; and the *chromous* compounds, CrCl_2 , CrO , etc., in which it is bivalent.

330. *Oxides.*—Chromium forms five oxides, containing CrO , Cr_3O_4 , Cr_2O_3 , CrO_2 , CrO_3 , the first three being analogous in composition to the three oxides of iron.

Chromous oxide, $\text{Cr}^{\text{II}}\text{O}$, is a powerful base, forming pale-blue salts, which absorb oxygen with extreme avidity.

Chromic oxide, Cr_2O_3 , gives a fine green tint to glass, and is used in enamel painting. It is a feeble base, resembling, and isomorphous with, ferric oxide and alumina; its salts (chromic salts) have a green or purple color, and are said to be poisonous.

331. *Chromic Sulphate.*—This salt, $\text{Cr}_2(\text{SO}_4)_3$, is prepared by dissolving the hydrated oxide in dilute sulphuric

acid. It unites with the sulphates of potassium and ammonium, giving rise to magnificent double salts, which crystallize in regular octohedrons of a deep-claret color, and possess a constitution resembling that of common alum, the aluminium being replaced by chromium. The finest crystals are obtained by spontaneous evaporation, the solution being apt to be decomposed by heat.

332. *Chromic Acid*. — Chromic trioxide, CrO_3 , in combination with water, forms *chromic acid*, H_2CrO_4 , which is bibasic and analogous in composition to sulphuric acid. Its salts are isomorphous with the corresponding sulphates.

333. *Potassic Chromate*. — This compound, K_2CrO_4 , forms yellow crystals, isomorphous with potassic sulphate. It dissolves in 2 parts of water at 15.5° .

334. *Potassic Dichromate*. — This salt, $\text{K}_2\text{Cr}_2\text{O}_7$, of which immense quantities are manufactured for use in the arts, especially in dyeing, crystallizes in beautiful red tabular crystals, derived from a prism. It melts when heated, and is soluble in 10 parts of water.

335. *Plumbic Chromate*. — On mixing solutions of potassic chromate or dichromate with plumbic nitrate or acetate, a brilliant yellow precipitate falls, which is plumbic chromate, PbCrO_4 , or *chrome-yellow*. It is extensively used as a paint.

336. *Argentichromate*. — This salt, Ag_2CrO_4 , precipitates as a reddish-brown powder when solutions of potassic chromate and argentic nitrate are mixed. It dissolves in hot dilute nitric acid, and separates, on cooling, in small ruby-red platy crystals.

URANIUM.

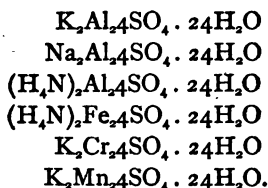
337. *Its Properties, etc.* — This metal is found in a few minerals, as *pitchblende*, which is an oxide, and *uranite*, which is a phosphate; the former is its principal ore.

The metal itself is obtained as a black coherent powder, or in fused white malleable globules, according to the manner in which the process is conducted. It is permanent in the air at ordinary temperatures, and does not decompose water; but in the pulverulent state it takes fire at 207° , burning brilliantly and forming a dark-green oxide. It unites, also, very violently with chlorine and with sulphur.

338. *Compounds of Uranium.* — Uranium forms an oxide, UO , which combines with chlorine and replaces hydrogen like a univalent radical. All the most important and characteristic compounds of uranium may be regarded as compounds of this radical, which is called *uranyl*. It acts as both a basic and an acid radical. The uranyl salts have generally a yellow color. The so-called *uranium oxide* is a hydrate of uranyl, retaining about 2 per cent of ammonia. It is used to impart a beautiful and peculiar yellow color to glass. Glass thus colored, and the transparent uranyl salts, are highly *fluorescent*.

339. *The Iron and Aluminium Group.* — The six elements, nickel, cobalt, manganese, iron, chromium, and aluminium, are closely related, and may perhaps be best regarded as forming one family with three subdivisions. The gradation of their chemical properties is best seen in their oxides. Nickel forms two oxides, NiO and Ni_2O_3 . The lower one of these alone is basic, the higher being both non-basic and very unstable. Cobalt, manganese, iron, and chromium each give two basic oxides; CoO , Co_2O_3 ; MnO , Mn_2O_3 ; FeO , Fe_2O_3 ; and CrO , Cr_2O_3 . The cobaltic and manganic salts are, however, quite unstable; while the ferrous salts are considerably less stable than the ferric salts, and the chromous salts have as little stability as the cobaltic. Aluminium does not form the lower oxide at all. We then see that the tendency of the atoms to combine in pairs so as to form sexivalent radicals increases as we pass from nickel to aluminium.

The sexivalent radicals, Mn_2 , Fe_2 , Cr_2 , and Al_2 , have a remarkable tendency to form double sulphates with the univalent metals, potassium, sodium, and ammonium. These highly crystallizable and isomorphous salts are called *alums*. The following table will illustrate the analogous composition of these salts : —



Nickel, cobalt, and manganese are somewhat magnetic, and closely resemble iron in many other qualities.

It is worthy of notice that all the metals of this group, except aluminium, form colored salts, independently of the color of the substance with which they unite.

Uranium is an element difficult to classify. It resembles chromium and the other metals of this group in many respects, but in other respects it is quite unlike them.

Judging from the uranyl compounds alone, we should conclude that uranium was a perissad closely allied to the nitrogen group ; but, on the other hand, we have a chloride, UCl_3 , and a series of *uranous* salts, in which one atom of the metal appears to replace two atoms of hydrogen. These would seem to indicate that uranium is an artiad element allied to iron ; and the fact that the native oxide, U_3O_8 , is isomorphous with the magnetic oxide of iron, sustains this view. "Uranium thus appears to stand between the nitrogen group of the perissad family, and the iron group of the artiad family. It belongs in a measure to both, and its compounds may be interpreted according to the one or the other plan of molecular grouping." *

* Cooke.

TIN GROUP OF METALS.

TIN.

340. *Its Reduction.* — The ores of tin — although this metal has been known from very early times — occur in but few localities, and the metallic tin is not found in nature. The chief European sources of tin are the Cornish mines, where it is found as *tin-stone*, SnO_2 . It was probably from these mines that the Phœnicians and Romans obtained all the tin which they employed in the manufacture of bronze. Tin-stone is also met with in Malacca and Borneo and Mexico. In order to prepare the metal, the tin-stone is crushed and washed to remove mechanically the lighter portions of rock with which it is mixed, and the purified ore is then placed in a reverberatory furnace, with anthracite or charcoal, and a small quantity of lime. The oxide is thus reduced, and the liquid metal, together with the slag, consisting of calcic silicate, falls to the lower part of the furnace. The blocks of tin, still impure, are then refined by gradually melting out the pure tin, leaving an impure alloy behind.

341. *Its Properties and Uses.* — Tin has a white color resembling that of silver; it has a density of 7.3, is soft, malleable, and ductile, but has little tenacity. When bent, pure tin emits a peculiar crackling sound. It melts at 237° , and is not sensibly volatile. Tin does not lose its lustre on exposure to the air, whether dry or moist, at ordinary temperatures; but if strongly heated, it takes fire, and a white powder of stannic oxide is formed.

Owing to its brilliancy, and its power of resisting ordinary atmospheric changes, tin is largely used for coating iron, copper, and other metals, which are more abundant and more easily oxidized. *Tin plate*, or *sheet tin*, as it is

called, is iron thus coated with tin. The thin sheets of iron are thoroughly cleaned with sulphuric acid, and then immersed in melted tin for an hour or so. Copper is tinned by brushing the melted tin over its surface, which must first be made perfectly clean.

Tin is sometimes used for water-pipes; and there is a popular impression that it is never acted upon by water. In certain localities, however, it oxidizes rapidly, and is soon rendered worthless. The safety of tin pipes, as compared with lead, does not consist in their exemption from corrosive action, but in the harmlessness of the resultant oxides and carbonates.

Tin is a tetrad metal, and forms two well-defined classes of compounds: the *stannous* compounds, in which it is bivalent; and the *stannic* compounds, in which it is quadrivalent.

342. *Chlorides*. — The *dichloride*, or *stannous chloride*, SnCl_2 , is a gray, resinous-looking substance, fusible below redness, and volatile at a high temperature.

The *hydrated chloride*, commonly called *tin-salt*, is easily prepared by dissolving metallic tin in hot muriatic acid. It crystallizes in needles containing $\text{SnCl}_2 \cdot 2\text{H}_2\text{O}$, which are freely soluble in a small quantity of water, but are apt to be decomposed in part when put into a large mass, unless muriatic acid in excess be present. Solution of stannous chloride is employed as a deoxidizing agent; it reduces the salts of mercury and other metals of the same class. It is also extensively employed as a *mordant* in dyeing and calico-printing; sometimes also as an *anti-chlore* (134).

The *tetrachloride*, or *stannic chloride*, SnCl_4 , is an old and very curious compound, formerly called *fuming liquor of Libavius*. It is a thin, colorless, mobile liquid, boiling at 120° , and yielding a colorless invisible vapor. It fumes in the air, and, when mixed with a third part of water,

solidifies to a soft fusible mass called *butter of tin*. The solution of stannic chloride is much employed by the dyer for the brightening and fixing of red colors. It is commonly prepared by dissolving metallic tin in a mixture of muriatic and nitric acids, care being taken to avoid too great elevation of temperature. The solution when evaporated yields a deliquescent crystalline hydrate, $\text{SnCl}_4 \cdot 5\text{H}_2\text{O}$.

343. *Oxides and Acids*. — The *monoxide*, or *stannous oxide*, SnO , is produced by heating stannous oxalate out of contact with the air; also by igniting stannous hydrate.

The *dioxide*, or *stannic oxide*, SnO_2 , occurs native as *tin-stone* or *cassiterite*, the common ore of tin, and is easily formed by heating tin, stannous oxide, or stannous hydrate, in contact with the air.

The *hydrate* formed by stannic oxide is remarkable for the different properties it exhibits when prepared in different ways. One form of it is insoluble in some acids and soluble with difficulty in others; while the other form is very readily soluble in acids. The latter is called *stannic acid*, and the former *metastannic acid*. The salts which they respectively form also differ in chemical properties, the *metastannates* being much less soluble in alkaline liquids than the *stannates*.

Sodic stannate, Na_2SnO_3 , is much used in calico printing as a *mordant*.

344. *Sulphides*. — The *monosulphide*, SnS , is prepared by fusing tin with excess of sulphur, and strongly heating the product. It is a lead-gray, brittle substance, fusible at a red heat, and soluble, with evolution of hydric sulphide, in hot muriatic acid.

The *disulphide*, SnS_2 , or *mosaic gold*, is prepared by exposing to a low red heat, in a glass flask, a mixture of 12 parts of tin, 6 of mercury, 6 of sal-ammoniac, and 7 of flowers of sulphur. Sal-ammoniac, cinnabar, and stannous

chloride sublime, while the disulphide remains at the bottom of the vessel in the form of brilliant gold-colored scales ; it is used as a substitute for gold powder.

TITANIUM.

345. *Its Properties, Compounds, etc.* — Titanium is one of the rarer elements, and is sometimes found associated with iron. It has never been obtained except in the form of a dark-green powder, which, under the microscope, shows the color and lustre of iron. In this form it is highly combustible. It readily dissolves in muriatic acid.

It forms a large number of *hydrates*, which may be arranged in two classes : (1) those which readily dissolve in acids, and when heated are dehydrated with vivid incandescence ; and (2) those which are insoluble in all acids except strong sulphuric, and which give off water more readily than the others and without incandescence.

346. *The Tin Group.* — The tin group consists of the two metals tin and titanium. These metals resemble each other in many of their compounds, and especially in their hydrates.

PLATINUM GROUP OF METALS.

PLATINUM.

347. *Its Ores and their Reduction.* — *Crude platinum*, a native alloy of platinum, palladium, rhodium, iridium, and a little iron, occurs in grains and rolled masses, sometimes tolerably large, mixed with gravel and transported materials, on the slope of the Ural Mountains in Russia, in Brazil, in Ceylon, and in a few other places. It is stated to be always present in small quantities with native silver.

The original mode of obtaining the metal was to dissolve

the ore in aqua-regia (nitro-muriatic acid), and precipitate the platinum (together with several of the accompanying metals) with sal-ammoniac, as the insoluble double chloride of ammonium and platinum, $2\text{H}_4\text{NCl}, \text{PtCl}_4$. This precipitate, when heated, yields metallic platinum in a finely divided or spongy state; and this sponge, if forcibly pressed and hammered when hot, gradually becomes a coherent metallic mass, the particles of platinum welding together, when hot, like iron. A new mode of preparing the metal has recently been proposed, the ore being melted in a very powerful furnace, heated with the oxy-hydrogen blowpipe. In this way a pure alloy of platinum, iridium, and rhodium is formed, the other constituents and impurities of the ore being either volatilized by the intense heat, or absorbed by the lime of which the crucible is composed. This alloy is in many respects more useful than pure platinum, being harder and less easily attacked by acids.

348. *Its Properties.* — Platinum has a bright white color, and does not tarnish under any circumstances in the air. Its specific gravity is 21.5. It is extremely infusible, and can only be melted by the heat of the oxy-hydrogen blowpipe, or in a very powerful blast-furnace made for the purpose. It dissolves in aqua-regia, but is not acted upon by the ordinary acids, and hence platinum vessels are much used in the laboratory. Caustic alkalies, however, act upon the metal at high temperatures. When finely divided, metallic platinum has the power of condensing gases upon its surface in a remarkable degree. When a mixture of oxygen and hydrogen is brought in contact with spongy platinum, or with *platinum-black*, the heat developed by the condensation of the gases is sufficient to ignite them.

Platinum forms two series of compounds: the *platinous* compounds, in which it is bivalent; and the *platinic* compounds, in which it is quadrivalent.

349. *Platinic Chloride.* — This compound, PtCl_4 , is al-

ways formed when platinum is dissolved in nitro-muriatic acid. It unites with a great variety of metallic chlorides, forming double salts called *platino-chlorides*. The most important of these compounds are those containing the metals of the alkalies and ammonium. *Potassic platino-chloride*, $2\text{KCl} \cdot \text{PtCl}_4$, forms a bright-yellow crystalline precipitate, being produced whenever solutions of the chlorides of platinum and of potassium are mixed, or a potassium salt mixed with a little muriatic acid is added to platinic chloride. It is feebly soluble in water, still less soluble in dilute alcohol, and is decomposed with some difficulty by heat. It is easily reduced by hydrogen, at a high temperature, yielding a mixture of potassic chloride and platinum-black; the latter substance being platinum in a state of very minute subdivision. The *sodium* salt, $2\text{NaCl} \cdot \text{PtCl}_4 \cdot 6\text{H}_2\text{O}$, is very soluble, crystallizing in large, transparent, yellow-red prisms of great beauty. The *ammonium* salt, $2\text{H}_4\text{NCl} \cdot \text{PtCl}_4$, is undistinguishable, in physical properties, from the potassium salt.

350. *Oxides*. — The *monoxide*, or *platinous oxide*, $\text{Pt}^{\text{II}}\text{O}_2$, dissolves in acids with brown color, and the solutions are not precipitated by sal-ammoniac. When platinic oxide is heated with solution of oxalic acid, it is reduced to platinous oxide, which remains dissolved. The liquid has a dark-blue color, and deposits fine copper-red needles of platinous oxalate.

The *dioxide*, or *platinic oxide*, $\text{Pt}^{\text{IV}}\text{O}_2$, dissolves in acids, and also combines with bases. The salts have a yellow or red tint, and a great disposition to unite with salts of the alkalies and alkaline earths, giving rise to a series of double compounds, which are not precipitated by excess of alkali. Platinic oxide and ammonia unite to form a compound which is explosive.

PALLADIUM.

351. *Its Properties.* — Palladium closely corresponds with platinum in color and appearance ; it is also very malleable and ductile. Its density differs very much from that of platinum, being only 11.8, and it is more easily oxidized than that metal. When heated to redness in the air, especially in the state of sponge, it acquires a blue or purple superficial film of oxide, which is again reduced at a white heat. This metal is slowly attacked by nitric acid ; its best solvent is nitro-muriatic acid.

Palladium, like platinum, forms two classes of compounds ; namely, the *palladious* compounds in which it is bivalent, and the *palladic* compounds, in which it is quadrivalent.

Palladium is readily alloyed with other metals,* as copper ; one of these compounds — namely, the alloy with silver — has been applied to useful purposes. An amalgam of palladium is now extensively used by dentists for stopping teeth.

A native alloy of gold with palladium is found in Brazil.

RHODIUM.

352. *Its Properties.* — Rhodium is very brittle ; reduced to powder and heated in the air it becomes oxidized, and the same alteration happens to a greater extent when it is fused with potassic nitrate or bisulphate. None of the acids, singly or conjoined, dissolve this metal, unless it be in the state of alloy, as with platinum, in which state it is attacked by nitro-muriatic acid.

An alloy of steel with a small quantity of rhodium is said to possess extremely valuable properties.

* For an account of the alloy which it forms with hydrogen, or *hydrogenium*, see foot-note on page 91.

IRIDIUM.

353. *Its Properties.* — Iridium is a white brittle metal, fusible with great difficulty before the oxy-hydrogen blow-pipe. Deville and Debray, by means of a powerful oxy-hydrogen blast furnace, have fused it completely into a pure white mass, resembling polished steel, brittle in the cold, somewhat malleable at a red heat, and having a density of 21.15. It forms three oxides, which readily pass one into another, giving rise to the variety of tints which characterize the solution of its salts. It is because of these changes of color that the metal is called *iridium*, from *iris*, the rainbow.

An alloy of iridium and osmium is very hard, and is used for the points of gold pens.

RUTHENIUM.

354. *Its Properties.* — Ruthenium is the most refractory of all metals except osmium. Deville and Debray have, however, fused it by placing it in the hottest part of the oxy-hydrogen flame. After fusion it has a density of 11.4.

Ruthenium is scarcely attacked by nitro-muriatic acid. It is, however, more easily oxidized than platinum, or even than silver.

OSMIUM.

355. *Its Properties.* — The properties of osmium vary according to its mode of preparation. In the pulverulent state it is black, destitute of metallic lustre, which, however, it acquires by burnishing; in the compact state it exhibits metallic lustre, and has a density of 10. Deville and Debray, by igniting precipitated osmic sulphide in a crucible of gas-coke, at the melting heat of nickel, obtained it in bluish-black, easily divisible lumps. When heated to the melting-point of rhodium, it becomes more

compact, and acquires a density of 21.3 to 21.4. At a still higher temperature, capable of melting ruthenium and iridium, and volatilizing platinum, osmium likewise volatilizes, but still does not melt; in fact, it is the most refractory of all metals.

356. *The Platinum Group.*—The six metals, platinum, palladium, iridium, rhodium, osmium, and ruthenium are usually called the *platinum metals*. They are all comparatively rare substances, and are always found in the native state, although more or less alloyed with one another. They are nearly infusible and have but slight affinities. Though decidedly metallic in many of their properties, they can hardly be said to form basic oxides. The metals of this group are even less basic than those of the last.

GOLD.

357. *Its Sources, etc.*—Gold, in small quantities, is a very widely diffused metal: traces of it are constantly found in the iron pyrites of the more ancient rocks. It is always met with in the metallic state, sometimes beautifully crystallized in the cubic form, associated with quartz, iron oxide, and other substances, in regular mineral veins. The sands of various rivers have long furnished gold derived from this source, and separable by a simple process of washing; such is the *gold-dust* of commerce. When a vein-stone is wrought for gold it is stamped to powder, and shaken in a suitable apparatus with water and mercury; an amalgam is thus formed, which is afterwards separated from the mixture and decomposed by distillation. Formerly, the chief supply of gold was from Brazil, Hungary, and the Ural Mountains; but California and Australia now yield by far the largest quantity. The new gold-field of British Columbia is also very productive.

Native gold is almost always alloyed with silver. The

purest specimens have been obtained from Schabrowski, near Katharinenburg in the Ural. A specimen analyzed by Gustav Rose was found to contain 98.96 per cent of gold. The Californian gold averages from 87.5 to 88.5 per cent, and the Australian from 96 to 96.6 per cent. In some specimens of native gold, as in that from Linarowski, in the Altai Mountains, the percentage of gold is as low as 60 per cent, the remainder being silver. There is also an auriferous silver found at Königsberg, in Hungary, containing 28 per cent of gold and 72 of silver.

358. *Its Properties.* — Gold is a soft metal, having a beautiful yellow color. It surpasses all other metals in malleability, the thinnest gold-leaf not exceeding, it is said, .000005 of an inch in thickness, while the gilding on the silver wire used in the manufacture of *gold-lace* is still thinner. It may also be drawn into very fine wire. Gold has a density of 19.5; it melts at a temperature a little above the fusing-point of silver. Neither air nor water affects it in the least at any temperature; the ordinary acids fail to attack it singly. It dissolves in presence of free chlorine, and in aqua-regia.

Gold intended for coin, and most other purposes, is always alloyed with a certain proportion of silver or copper, to increase its hardness and durability. English standard gold contains $\frac{1}{12}$ of alloy, now always copper. The purity of gold is commonly expressed in *carats*. Pure gold is said to be 24 *carats fine*; an alloy containing $\frac{23}{24}$ of pure gold is called 23 *carats fine*; $\frac{18}{24}$ of pure gold (the finest usually employed for jewelry), 18 *carats fine*; and so on.

Gilding on copper has very generally been performed by dipping the articles into a solution of mercuric nitrate, and then shaking them with a small lump of a soft amalgam of gold and mercury, which thus becomes spread over their surfaces; the articles are subsequently heated to expel the mercury, and then burnished. Gilding on steel is done

either by applying a solution of auric chloride in ether, or by roughening the surface of the metal, heating it, and applying gold-leaf with a burnisher. Gilding by electrolysis is a simple method, now rapidly superseding many of the others. The solution usually employed is obtained by dissolving auric cyanide in a solution of potassic cyanide.

Gold forms two series of compounds: the *aurous* compounds, in which it is univalent; and the *auric* compounds, in which it is trivalent.

359. *Auric Chloride*. — The *trichloride*, AuCl_3 , is the most important compound of gold; it is always produced when gold is dissolved in nitro-muriatic acid. The deep-yellow solution thus obtained yields, by evaporation, yellow crystals of the double chloride of gold and hydrogen: when this is cautiously heated, muriatic acid is expelled, and the residue, on cooling, solidifies to a red crystalline mass of auric chloride, very deliquescent, and soluble in water, alcohol, and ether. Auric chloride combines with a number of metallic chlorides, forming a series of double salts, called *chloro-aurates*, of which the general formula in the anhydrous state is $\text{MCl} \cdot \text{AuCl}_3$, M representing an atom of a monad metal. These compounds are mostly yellow when in crystals, and red when deprived of water.

A mixture of auric chloride with excess of acid potassic or sodic carbonate is used for gilding small ornamental articles of copper; these are cleaned by dilute nitric acid, and then boiled in the mixture for some time, by which means they acquire a thin but perfect coating of reduced gold.

360. *Oxides*. — The *monoxide*, or *aurous oxide*, Au_2O , is a green powder, with very feeble basic properties.

The *trioxide*, or *auric oxide*, AuO_3 , is a reddish-yellow insoluble powder, which when dry becomes chestnut-brown. It is easily reduced by heat, and also by mere exposure to light; it is insoluble in oxygen acids, with the

exception of strong nitric acid, insoluble in hydrofluoric acid, easily dissolved by muriatic acid. Alkalies dissolve it freely; indeed, the acid properties of this substance are very strongly marked. It forms salts called *aurates*. When digested with ammonia, it yields *fulminating gold*, consisting, according to Berzelius, of $(\text{NH}_3)_4\text{Au}_2\text{O}_3 \cdot \text{H}_2\text{O}$.

Gold shows but little tendency to form oxygen salts. Auric oxide dissolves in strong nitric acid, but the solution is decomposed by evaporation or dilution. A *sodio-aurous hyposulphite*, $\text{AuNa}_3(\text{S}_2\text{O}_3)_2 \cdot 2\text{H}_2\text{O}$, is prepared by mixing the concentrated solutions of auric chloride and sodic hyposulphite, and precipitating with alcohol. It is very soluble in water, and crystallizes in colorless needles. Its solution is used for fixing daguerreotype pictures.

361. *The Chemical Relations of Gold.* — The metal gold, like the non-metal boron, stands by itself. It is usually called the king of metals, yet it scarcely forms a basic oxide. In each of the two great divisions of the elements there are certain metals which occupy an intermediate position, from which we gradually pass to the well-marked non-metals on the one side and the well-marked metals on the other. Thus the *perissads* bismuth and gold are in their chemical relations but indifferent metals; and from these we pass, through antimony and arsenic, to chlorine on the one side, and, through thallium and silver, to potassium on the other. Again in the *artiads* we pass from the platinum metals, through silicon and carbon, to sulphur on one side, and, through tin and aluminium, to calcium on the other.

THE RARER METALS.

362. *Tungsten*, or *wolfranium* (W), forms with steel an alloy of remarkable hardness. WO_3 , or *tungstic acid*, combines with sodium to form *sodic tungstate* (*tungstate of soda*), Na_2WO_4 , which is used in calico-printing, and in combina-

tion with starch to render linen and cotton fabrics incombustible.

The other metallic elements are very rare substances, and as yet are of little practical importance.

SUMMARY OF THE METALS.

Sodium. — Soft white metal with brilliant lustre, but quickly tarnishing in the air. Decomposes water at the lowest temperature. Burns readily in the air, with an intense yellow flame. Found in nature in common salt and in a few other minerals. Used in the extraction of aluminium, and in the treatment of gold ores. Forms very important salts; common salt is sodic chloride; sal-soda, sodic carbonate; caustic soda, sodic hydrate; and cubic saltpetre, sodic nitrate.

Potassium. — Resembles Na, but more active. More costly, and therefore less used. An important constituent of felspar and mica, two very widely distributed minerals. A constituent also of fertile soils, from which it is absorbed by plants, whose ashes are the chief source of the potassium salts. These salts are now also obtained from the salt-beds of Stassfurt, Germany. Potash is potassic carbonate; caustic potash, potassic hydrate; and nitre, potassic nitrate. Nitre is a natural product, and is chiefly used in the manufacture of gunpowder.

Lithium, Rubidium, Cesium. — Found in very minute quantities in certain mineral waters and in a few rare minerals. Always associated with Na and K, with which they have close chemical relations. With those metals they form a series of electro-positive elements quite as well marked as the chlorine series of electro-negative elements.

Silver. — Found in small quantities in nature, chiefly in the metallic state. Does not oxidize when heated in the air. The nitrate is the most important soluble salt. The chloride in contact with organic matter blackens in the light. On this property is based the ordinary process of photographic printing. In presence of an excess of nitrate, and after exposure to light, the bromide and iodide are at once reduced to a metallic state by solution of ferrous sulphate. Before exposure the reduction takes place very slowly. On this reaction is based the art of photography.

Thallium. — A very rare element, whose vapor imparts a green color to the flame of a Bunsen lamp, and shows a single green band in the spectroscope.

Calcium. — One of the most abundant constituents of the crust of the earth. A soft, malleable metal, with a reddish tinge. Readily tarnishes in the air. Burns when heated. Decomposes water at all temperatures. Obtained in a free state with great difficulty. All the varieties of limestones are calcic carbonate. Gypsum, alabaster, and plaster of Paris, are calcic sulphate. The chief earthy constituent of bones is calcic phosphate. Quicklime is calcic oxide; and bleaching-powder, calcic oxychloride, CaOCl_2 . Fluorspar is calcic fluoride.

Strontium and Barium. — These elements are closely allied to Ca, with which they form a chemical series. Far less abundantly distributed in nature than Ca. Not used in the free state. Their salts are used in making fireworks.

Lead. — One of the more abundant metallic elements. Principal ore is galena. So soft that it can be moulded by pressure. Extensively used in the arts, both pure and alloyed with other metals. Type metal, britannia metal, and solder, the most important of these alloys. *White lead* is plumbic carbonate; *red lead*, a mixture of plumbic oxide and peroxide; and sugar of lead, plumbic acetate.

Litharge (plumbic oxide) is much used for making flint glass, for glazing earthenware, and for preparing various paints and lead salts.

Magnesium. — One of the most widely distributed elements. Less abundant than Ca, with which it is usually associated, and to which it is very closely allied in some of its relations. Obtained by decomposing the chloride with metallic Na. A silver-white metal, melting at a red heat, and volatilizing at a high temperature in an atmosphere of H. Malleable, ductile, and susceptible of a high polish. Does not tarnish in dry air. At a high temperature burns with great splendor. Much used as a source of pure white light, where great brilliancy is required. *Magnesia alba* is a mixture of magnesian carbonate and magnesian hydrate. Epsom salt is magnesian sulphate.

Zinc. — One of the more abundant metals. Fuses at 412° . Boils at a red heat. The polished surface has a bright lustre, with a bluish tint, but soon tarnishes. Has a crystalline structure, and is brittle at most temperatures. Readily rolled into sheets at a temperature of about 140° . Sheet zinc is nearly as cheap as sheet-iron, and does not rust so fast. Iron, which is stronger, is often coated with zinc to keep it from rusting. It is then said to be *galvanized*. Zincic oxide is much used as a white paint. White vitriol is zincic sulphate.

Indium and Cadmium. — Two rare metals associated with Zn: indium seldom and in very small quantities, cadmium oftener and in much larger amount. The three form a well-defined group.

Copper. — One of the earliest known, most abundant, and most useful of the metals. The most important ore is copper pyrites. Near Lake Superior is found native in great quantities. Has a brilliant lustre and a reddish color. Is very hard, tenacious, ductile, and malleable, and one of the best conductors of heat and electricity. Does not oxi-

dize in the air at ordinary temperatures. Brass and yellow metal are alloys of Cu and Zn. Bronze, bell metal, gun metal, and speculum metal are all essentially alloys of Cu and Sn. Several copper compounds are much used as paints. Blue vitriol is cupric sulphate. Copper has the remarkable property of replacing a portion of the H in certain of the compounds of ammonium.

Mercury. — Not widely distributed, but abundant in a few localities, as at Idria in Austria, Almaden in Spain, New Almaden in California, and Huancavelica in Peru. Cinna-bar, HgS , the principal ore. The only metal liquid at the ordinary temperature. Has a brilliant metallic lustre, and a silver-white color. Malleable when solid. Does not oxidize in the air at the ordinary temperature, and only slowly at a high temperature. Chiefly used in the treatment of gold ores. Also used for silvering mirrors, for making philosophical instruments, etc. Calomel is mercurous chloride; and corrosive sublimate, mercuric chloride. Like Cu, mercury can replace a portion of the H in certain compounds of H_4N .

Nickel. — One of the less abundant metals. Not easily reduced. Has a silver-white color, a brilliant metallic lustre, and does not tarnish in the air. Is very tenacious and malleable, and would rival even Fe in usefulness, were it more abundant. Resembles Fe in many of its qualities. It is magnetic, and is a constant constituent of metallic meteorites. Forms, with Cu, a hard, tenacious, malleable alloy, used in coinage, and as the basis of the better kinds of electrotype plate. A small amount of Ni whitens a large body of Cu. German silver is an alloy of Cu, Zn, and Ni.

Cobalt. — Associated with Ni in the same ores, but in smaller quantities. Resembles Ni in chemical relations. Zaffre is an impure oxide of Co. *Thénard's blue* is a compound of cobaltic oxide and alumina; *Reinman's green*, a

compound of cobaltous and zincic oxides. Cobaltous oxide gives an intense blue to glass. *Smalt* is a glass highly colored with cobaltous oxide. Ni and Co both form a number of complex compounds with the ammoniac salts.

Manganese. — A tolerably abundant and widely diffused metal. Very hard and brittle. Has a grayish-white color, is almost infusible, and very slightly magnetic. Is not used in the metallic state. Forms a large number of oxides. The black oxide is much used in preparing Cl.

Iron. — A universally diffused element. The most abundant and important of the useful metals. Wrought-iron is nearly pure metal. It is so soft that it can readily be worked with files and other tools. It is very tenacious, ductile, and malleable, and can be welded at a white heat. Cast-iron contains 4 or 5 per cent of C, and is harder and more brittle than wrought-iron; also melts at a lower temperature. Steel is intermediate between wrought and cast iron in composition and physical properties. Fe forms two classes of compounds, the *ferrous* and the *ferric*. Green vitriol is ferrous sulphate.

Chromium. — Not used in the metallic state. Many of its compounds have a brilliant color, and are used as paints. Like Fe, it forms two classes of compounds. *Chrome green* is chromic oxide. *Chrome yellow* is plumbic chromate, and *chrome orange* diplumbic chromate (Pb_2CrO_5).

Aluminium. — After O and Si, the most abundant constituent of the rocky crust of the globe. Found chiefly in combination with O and Si. Obtained by reducing the chloride with metallic Na. Has a brilliant white lustre; is very light, but very tenacious, very malleable and ductile, and singularly sonorous. Does not tarnish in the air. At present too costly for general use. *Aluminium bronze*, an alloy of Cu with about 10 per cent of Al, has the color of gold, and almost its power of resisting atmospheric agents. Soluble salts of Al are generally prepared from

the clays and the clay slates. *Alum* is potassio-aluminic sulphate ; much used as a mordant.

Platinum. — Comparatively rare. Found in many countries, but chiefly in the Ural Mountains. Nearly infusible, and acted upon by none of the acids singly, and but slowly by aqua-regia. Very ductile and malleable, and capable of welding at a white heat. Chiefly used for making chemical vessels, and for the passive plate in Grove's galvanic battery.

Ruthenium, Osmium, Rhodium, Iridium, and Palladium. — Rare metals, associated with Pt, to which they are closely allied.

Tin. — Distribution in nature very limited. Has a white color and a bright lustre. Has feeble tenacity, but may be beaten into thin leaves, or *tin-foil*. On account of its lustre and its power of resisting atmospheric agents, much used for coating other metals. Common sheet-tin is iron thus coated. Mirrors are silvered with an amalgam of Sn and Hg.

Titanium. — A rare metal, allied to Sn.

Gold. — Almost always found in the native state. Very widely, but very sparingly, diffused in nature. Has a brilliant yellow lustre, which it preserves under all ordinary conditions. With the exception of Pt, Ir, and Os, the densest solid known. Attacked by no ordinary acid. Exceedingly malleable ; nearly as soft as Pb ; when pure may be welded without heat, by simple pressure or hammering, as in dentistry. Is alloyed with Cu, to increase its hardness. *Purple of Cassius* is a compound of Au, Sn, and O.

Vanadium and Uranium. — Rare metals, somewhat allied in their chemical relations.

CHEMISTRY OF THE ATMOSPHERE.

COMBUSTION.

363. *Composition of the Atmosphere.* — We live at the bottom of an aerial ocean called the *atmosphere*, which is some fifty miles in depth. This atmosphere contains free oxygen, as may be shown by inverting a jar of it over a jar of nitric oxide (147).

We have seen (141) that the free oxygen can be removed from air by burning phosphorus in a jar of air over water. After all the oxygen has combined with the phosphorus, and the compound formed has been absorbed by the water, the jar is found to be about one fifth filled with water, showing that about one fifth of the air is oxygen.

The gas left in the jar is almost pure nitrogen.

Besides the oxygen and nitrogen, there is a small quantity of *carbonic anhydride*, as may be shown by passing a large volume of air through lime-water. There is also *watery vapor*, which is continually condensed in the form of rain and dew. Traces of *ammonia* and of *nitric acid* are also found, and to these are to be added the exhalations continually rising from the earth. The whole quantity of these minor ingredients, with the exception of watery vapor, does not amount to more than one part in a thousand. The proportions of oxygen and nitrogen are almost invariable, while those of the other ingredients are continually fluctuating.

The quantity of carbonic acid contained in the air can be

found by drawing a known volume of perfectly dry air (not less than 20 litres) through weighed tubes containing caustic potash; the increase in the weight of the tubes is the weight of carbonic acid in the air drawn through.

The amount of watery vapor contained in the air at any time can be determined in a similar way by passing air through tubes filled with pumice-stone moistened with sulphuric acid. In general the air contains from 50 to 70 per cent of the quantity necessary to saturate it. If the quantity be not within these limits, the air is either unpleasantly dry or moist.

It must be borne in mind that the atmosphere is not a chemical compound, but merely a *mixture* of these different gases. "Indeed, we may regard the globe as surrounded by at least three separate atmospheres, — one of oxygen, one of nitrogen, and one of aqueous vapor, — all existing simultaneously in the same space, yet each entirely distinct from the other two, and only very slightly influenced by their presence."

The following Tables are from Miller :—

Composition of the Atmosphere.

Oxygen	20.61
Nitrogen	77.95
Carbonic Acid . . . . .	.04
Watery Vapor (average)	1.40
	<hr/>
	100.00

Composition in Tons.

Oxygen	1,233,010	billions	of tons.
Nitrogen	3,994,593	"	"
Carbonic Acid	5,287	"	"
Watery Vapor	54,460	"	"

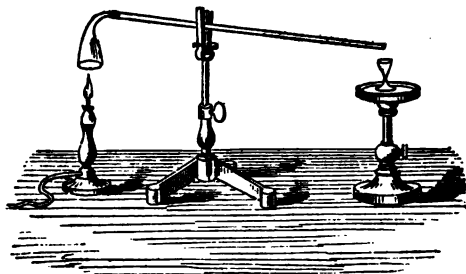
364. *The Products of the Burning of a Candle or Coal-Gas are Carbonic Acid and Water.* — When a lighted taper

is held to a candle, or to a jet of coal-gas, the latter takes fire. In what does its burning consist?

Invert a bottle for a short time over the candle or gas-burner; then remove it, pour in a little lime-water, close the mouth of the bottle with the hand, and shake it. The lime-water becomes milky-white, showing that *carbonic anhydride* has been produced by the burning.

If the candle or gas be burnt under a tin funnel connected with a long glass tube (which must be kept cold), moisture will collect on the inside, and, after a short time, will trickle down, and drop from the end of the tube. If the liquid from the tube be tested with a bit of potassium, it proves to be water, which is therefore another product of the burning.

Fig. 53.



No other substance is produced, except in very minute quantities, by the burning of the candle or the gas.

365. *The Candle, in Burning, removes Oxygen from the Air.* — Arrange a candle, so that it can be covered with a bell-jar, over the water-trough; then light it, and cover it with the jar. It soon ceases to burn, and the water rises in the jar. The burning, then, removes something from the air.

Put a lighted candle into air from which the oxygen has been removed, and it is at once extinguished, showing

that it cannot burn without oxygen. It must, then, be oxygen which it removes from the air when it burns.

366. *All Ordinary Combustion consists in the Combination of the Oxygen of the Air with the Burning Substance.*

— We have seen that carbonic anhydride, CO_2 , and water, H_2O , are the products of the burning of a candle. Of the three elements in these products, the O, as we have seen, comes from the air; the C and H exist in the candle.

Experiments similar to those which we have tried with the candle will show that any ordinary combustible substance removes oxygen from the air when it burns, and that it cannot burn without oxygen. We conclude, then, that all ordinary combustion is the combination of the oxygen of the air with the burning body.

367. *Why a Draft is necessary in Stoves and Furnaces.*

— Since combustion is the combination of oxygen with the burning body, we see why our stoves and furnaces must have a draft. As fast as the oxygen is taken from the air by the burning fuel, this air must be removed, and a fresh supply must take its place. In other words, a stream of air must be kept constantly flowing over or through the fuel.

We see, also, how the fire can be regulated by means of the draft. If the doors or dampers through which the air is admitted be partially closed, the supply of air will be diminished, and the burning will therefore be retarded.

368. *Combustibles and Supporters of Combustion.* — Any substance, as coal-gas, which can be made to burn, is called a *combustible*; while any substance, as air or oxygen, in which it can burn, is called a *supporter of combustion*. These terms are convenient, though, strictly speaking, the one substance is no more a combustible or a supporter of combustion than the other. Since the burning of coal-gas consists in the combination of the gas with oxygen, the oxygen in reality burns, as well as the gas; and, on the other hand, the gas is as much a supporter of the com-

bustion as the oxygen. The burning must of course take place where the gases come together. A jet of oxygen would appear to burn in an atmosphere of coal-gas, just as a jet of coal-gas appears to burn in an atmosphere of oxygen.

Fig. 54.



Fit a cork to one end of a lamp chimney, and let the tip of a gas-burner pass through it, as represented in the figure. Allow the gas to escape for some time, and then light it at the top of the chimney. It will burn quietly, and the

chimney will evidently be filled with coal-gas. Fill a gas-bag with oxygen, and fasten to the bag a bent glass tube drawn out into a fine jet. Force the oxygen through the tube in a gentle stream, and introduce the end of the tube through the flame into the chimney. As it passes the flame, the oxygen takes fire and burns brightly in the coal-gas; the oxygen apparently becoming the combustible body, and the coal-gas the supporter of combustion.

In both the flames which we have here, it will be seen that gases are burning where they come together;—the coal-gas and the oxygen of the air, where they meet at the top of the chimney; the oxygen from the bag and the coal-gas, where they meet at the end of the tube.

369. *Oxygen must be Heated before it will combine with Ordinary Combustibles.*—The jet of coal-gas has no disposition to burn until a lighted taper is applied to it. The oxygen of the air is at all times in contact with wood and coal, yet they do not burn unless they are first kindled. When even as inflammable a gas as hydrogen is mixed with

oxygen, it does not burn unless ignited with a taper or an electric spark. "At the ordinary temperature of the air its chemical affinities are dormant; and, although endowed with forces which are irresistible when in action, it awaits the necessary conditions to call them forth. One of the grandest works of ancient art which have come down to us is the colossal statue of the Farnese Hercules. The hero of ancient mythology is represented in an erect form, leaning on his club, and ready for action; but at the moment every one of the well-developed muscles of his ponderous frame is fully relaxed, and the figure is a perfect ideal of repose, yet a wonderful embodiment of power. Here in this antique we have most perfectly typified the passive condition of oxygen, the hero of the chemical elements. Raise now the temperature to a red heat, and in a moment all is changed. The dormant energies of its mighty powers are aroused, and it rushes into combination with all combustible matter, surrounded by those glorious manifestations of light and heat which every conflagration presents." — COOKE.

370. *Combustion is Self-sustaining.* — It is not necessary to arouse any large amount of oxygen to activity in order to insure the continuance of the combustion. When, for instance, a lighted match is held to the wick of a candle, it excites but a few molecules of oxygen to activity. These few rush into combination with the elements of the candle, and by so doing develop sufficient heat to awaken the activity of more oxygen, which in turn enters into combination and develops more heat. In this way a supply of active oxygen is maintained until the candle is consumed.

371. *The Point of Ignition.* — Different substances begin to burn at very different temperatures. This is well illustrated in the kindling of a coal fire. Shavings are put into the grate first, then kindling-wood, then charcoal, and finally

hard coal. The shavings are lighted by means of a match. The match is a bit of dry, soft wood, one end of which is covered with sulphur and tipped with phosphorus. It is a well-known fact, that when two bodies are rubbed together heat is developed. On striking the match sufficient heat is developed by the friction to ignite the phosphorus, which takes fire at a temperature of about 150° Fahrenheit. The phosphorus in burning develops heat enough to ignite the sulphur, which burns at a temperature of about 500° . The burning sulphur develops heat enough to ignite the wood of the match; the match, to ignite the shavings; the shavings, the kindling-wood; the kindling-wood, the charcoal; and the charcoal, the hard coal, which requires the temperature of a full white heat to set it on fire.

372. *The Products of Combustion are not always Gaseous.* — In the burning of coal-gas and of a candle, the products are wholly gaseous, and in the burning of wood they are mainly gaseous; but when metals, as copper and iron, burn in the oxy-hydrogen flame, the products of their combustion are seen to be *solid*.

We have already learned that many of the rare metals, as magnesium and calcium, burn readily in the air. They are as combustible as carbon; but they differ from carbon in giving rise to solid products while burning.

373. *Oxygen is not the only Supporter of Combustion.* — We have seen (97) that copper foil and pulverized antimony will also burn in chlorine. Many metals will burn in the vapor of sulphur. The burning in these cases is a combination of the metal with chlorine or with sulphur.

374. *The Materials of the Earth's Crust are chiefly Products of Combustion.* — We find in marble (186) two very combustible substances, calcium and carbon, combined with oxygen. The rocks and solid matter of the earth are made up chiefly of such combustible elements as potassium, calcium, magnesium, aluminium, and carbon, com-

bined with oxygen. The fact that these metals are so rare in a free state is due to their extreme combustibility. It is very difficult to separate them from oxygen, and no less difficult to keep them separate.

Water, as we know, is also made up of very combustible elements. There must have been a time when the elements of all these solid and liquid materials of the earth existed together in a free state. Then, by some means unknown to us, the mass took fire, and the conflagration raged until all the materials were consumed. There was more oxygen than was needed for the combustion ; and this is now found in the air in a free state. Oxygen was the most abundant of all the elements, since it alone makes up half the weight of the solid earth, eight ninths the weight of the water, and one fifth the weight of the atmosphere.

SLOW COMBUSTION.

375. *Partially Active Condition of Oxygen.* — Besides its active and passive states, oxygen exists in a third or intermediate condition, in which it is *partially* active. In this form it plays a very important part in nature. It acts silently and slowly, taking months, and even years, to accomplish its work ; but the results "far surpass in true grandeur those dazzling displays of power which the fire-element manifests when fully aroused."

376. *Decay.* — When wood, or any other *organic* substance, is exposed to moist air it *decays*. It first becomes rotten, and then slowly disappears. This decay consists in a gradual union of the substance with oxygen ; in other words, a *slow combustion*. A log of wood which rots in the forest undergoes the very same change as one which is burnt on the hearth ; the sole difference being that, while the latter burns up in a few hours, the former is consumed only after the lapse of many years.

Wood, like other vegetable compounds, consists mainly of carbon, hydrogen, and oxygen. When it burns on the hearth, its carbon and hydrogen combine with the oxygen of the air, forming carbonic acid and water, which pass off in the smoke. The hydrogen is more combustible than the carbon, and therefore burns first, leaving the carbon in the form of glowing coals. These are consumed in their turn, gradually smouldering away, until nothing is left but a little ashes.

Quite the same process is going on with the decaying log in the forest. In decay, as in burning, the hydrogen of the wood unites with the atmospheric oxygen sooner than the carbon does; hence, in this stage of its decay, the wood becomes darker, and more like charcoal. At length, both the hydrogen and the carbon are burnt; and the log is slowly converted into carbonic acid and water, leaving only a handful of earth as the *ashes* of this lingering combustion. Even the *heat* generated in this form of burning is found to be precisely the same as in ordinary combustion; the only difference being that, in the latter case, it is all set free in a few hours, while in the former it is so slowly developed that it escapes our notice.

377. *Causes of Decay.*—Green wood decays much sooner than dry wood. Indeed, if wood be kept perfectly dry, it will not decay for ages. In the dry climate of Egypt, wooden mummy-cases have been preserved for more than three thousand years.

The decay of the green wood is due to the presence of what are called *albuminous* substances. The most important of these is *vegetable albumen*, and it is essentially the same thing as the albumen (or *white*) of an egg. We have said that most vegetable substances are made up of carbon, hydrogen, and oxygen; but these albuminous compounds, which form only a small part of the bulk of plants, contain an additional element, *nitrogen*. We know that

the compounds of nitrogen are generally very unstable, and these albuminous substances are peculiarly so. In the presence of moisture they soon *putrefy*, or break up into simpler compounds. The oxygen of the air takes no part in this process, but, by contact with the putrefying substance, it is, in some mysterious way, awakened to the state of partial activity mentioned above. It is thus enabled to attack and consume the wood and all the other organic compounds present. The decay, or slow combustion, once begun, is self-sustaining, fresh portions of oxygen being continually roused to activity by the process itself, precisely as in ordinary burning.

When the nitrogenized vegetable compounds are *burnt*, the nitrogen passes off in a *free* state ; when they *decay*, it escapes, combined with hydrogen as *ammonia*.

378. *Rusting*. — Rusting is the slow combustion of a metal, and, like other kinds of slow combustion, it develops heat. This is shown by the fact that, if a large pile of iron-filings be moistened and exposed to the air, so that they rust rapidly, the temperature rises perceptibly.

A remarkable case of heat developed by rusting occurred in England during the manufacture of a submarine electric cable. The copper wire of the cable was covered with gutta-percha, tar, and hemp, and the whole enclosed in a casing of iron wire. The cable as it was finished was coiled in tanks filled with water ; these tanks leaked, and the water was therefore drawn off, leaving about 163 nautical miles of cable coiled in a mass 30 feet in diameter (with a space in the centre 6 feet in diameter) and 8 feet high. It rusted so rapidly that the temperature in the centre of the coil rose in four days from 19° to 26° , though the temperature of the air did not rise above 19° during the period, and was as low as 15° part of the time. The mass would have become even hotter, had it not been cooled by pouring on water.

379. *Spontaneous Combustion*. — When charcoal which has been finely pulverized for making gunpowder is exposed in large heaps, the oxygen of the air combines with it slowly at first ; but, as the heat developed accumulates, the oxidation becomes more rapid, until in some cases the mass takes fire and burns.

So, too, when cotton or tow, which has been used for wiping machinery, and has become saturated with oil, is laid aside in heaps, it begins to oxidize slowly ; but the heat developed causes the combustion to go on more and more rapidly, until sometimes the heap bursts into a flame.

This rapid combustion, developed gradually from slow combustion, is called *spontaneous combustion*.

380. *Respiration*. — The albuminous or *nitrogenized* compounds, which form but a small part of the plant, make up almost the entire bulk of the animal, so that animal substances are even more prone to decay than vegetable. And this decay is not confined, as we might suppose, to *dead* animal matter, but is constantly going on in the *living* animal. The only difference is, that in the latter case the loss from decay is continually repaired, while in the former case it is not. The materials for the repair of the living body are furnished by the *food*.

This food is mainly made up of three classes of substances : (1) *non-nitrogenized*, as starch and sugar ; (2) *nitrogenized*, as lean meat ; and (3) *fatty* substances, as butter. All three kinds are absolutely necessary to the life of man. They are all contained in *milk*, which may be regarded as "the type of animal food." It contains *sugar*, which belongs to the first of the above classes ; *caseine*, or *curd*, which belongs to the second ; and *butter*, which belongs to the third. Bread also contains all three kinds of food, being made up of (1) *starch*, (2) *gluten* (the most important nitrogenized constituent of wheat and other grain), and (3) a small quantity of

oil. A man cannot live for any length of time on any one kind of food, as starch or butter, or on any mixture of kinds of food, which does not contain all three classes of substances.

The different classes of food serve different purposes in the body. The *nitrogenized* and a part of the *fatty* substances supply the waste which results from the action of the varied machinery of the body. They renew the muscles, sinews, and nerves, which are constantly wearing out. On the other hand, the non-nitrogenized substances, as starch and sugar, probably take no part in repairing the machinery, but merely furnish fuel to keep up the heat of the body. To produce heat they must be burnt up, and we shall see that the process is another example of *slow combustion*.

Starch and sugar make up by far the greatest part of this fuel, and in fact of our food generally. They are almost identical in composition, and starch can readily be converted into sugar. When taken into the stomach, starch undergoes this change, and the sugar then readily dissolves in the water present. The solution is absorbed by the veins, and becomes mingled with the blood, which carries it to the heart. By the heart, which is made up of two force-pumps, the blood is forced through the lungs. These are composed of millions of little membranous bags or *air-cells*, closely packed together, and all connected by means of tubes with the windpipe, and thus with the nose and mouth. The membrane of the cells is very thin, so that they are easily compressed. The whole mass of the lungs is also very elastic, and by the action of muscles they are alternately expanded and contracted as we breathe. When they expand the air from without rushes in and fills the cells; and when they contract, this air is forced out again.

We have said that the blood charged with sugar is

forced through the lungs. The tube, or *artery*, which conveys it divides and subdivides, until it is reduced to very small capillary tubes, which form a delicate network on the surfaces of the air-cells. The walls of these capillaries are very thin, and the oxygen of the air readily passes through them, by *osmose* (45), and mingles with the blood. At the same time, and in the same way, carbonic acid is given out by the blood, and mixes with the air. The blood, holding in solution both sugar and oxygen, now goes back to the heart; and by the second force-pump it is sent to all parts of the body. In the mean time the sugar is burnt up by the oxygen which was absorbed in the lungs.

"Sugar, like wood, consists of carbon, hydrogen, and oxygen. The last two are present in the proportions to form water, so that sugar may be said to be composed of charcoal and water. Of these two substances, the charcoal only is combustible. This, during the circulation of the blood, is slowly burnt up by the dissolved oxygen, and converted into carbonic acid, which remains in solution until it is discharged when the blood returns again to the lungs, or else escapes through the skin."*

Respiration, then, is a kind of combustion, in which "the fuel is sugar, and the smoke carbonic acid and aqueous vapor." The presence of carbonic acid in the air from the lungs may be proved by breathing through a glass tube into lime-water, which soon becomes milky. The presence of the watery vapor may be shown by breathing upon any cold substance.

The weight of carbonic acid breathed out by a full-grown man in a day varies from 1 to 3 pounds, or from 9 to 27 cubic feet; and the weight of carbon burned is from

* Cooke's "Religion and Chemistry." The greater part of §§ 375 - 377 and 380 - 382 has been condensed from the 3d and 4th Lectures in this admirable series.

5 to 15 ounces. The amount of heat produced is of course the same as would be set free by burning the same weight of charcoal in a stove. The temperature of the body is thus kept above that of the air; the heat of the blood, even in the coldest climate, being maintained at 96° .

"In regulating the temperature of his body, man follows instinctively the same rules of common sense which he applies in warming his dwellings. In proportion as the climate is cold, he supplies the loss of heat by burning more fuel in his lungs, and hence the statements of arctic voyagers—who have told us that twelve pounds of tallow candles make only an average meal for an Esquimau—are not inconsistent with the deductions of science."

381. *Slow and Rapid Combustion of Sugar.*—We may compare the rapid combustion of sugar in air with its slow combustion in the body by the following experiment: Take 2 ounces of pulverized sugar, or the average quantity burnt in the body of a man in an hour, and mix it with $5\frac{1}{2}$ ounces of pulverized potassic chlorate. We have, then, the sugar and the solidified oxygen of the chlorate mingled as in the blood; but the oxygen is passive, and will not combine with the sugar until roused to activity. A single drop of sulphuric acid let fall upon the mixture serves to awaken its dormant energy, and the mass is consumed in an instant, with intense evolution of heat and light. The amount of heat concentrated in this momentary burst of flame is no greater than would have been generated in the blood in the course of an hour.

"The splendid displays of combustion arrest our attention by their very brilliancy, while we overlook the silent yet ceaseless processes of respiration and decay, before which, in importance and magnitude, the greatest conflagrations sink into insignificance. These are but

the spasmodic efforts of nature; those, the appointed means by which the harmony and order of creation are preserved."

382. *The Daily Consumption of Oxygen in Nature.* — Faraday has roughly estimated that the amount of oxygen required daily, to supply the lungs of the human race, is at least one thousand millions of pounds; that required for the respiration of the lower animals is at least twice as much as this; while the always active processes of decay require certainly no less than four thousand millions of pounds more, — making a total aggregate of seven thousand millions of pounds required to carry on these processes of nature alone. Compared with this, the one thousand millions of pounds which, as Faraday estimates, are sufficient to sustain all the artificial fires lighted by man, from the camp-fire of the savage to the roaring blaze of the blast-furnace, or the raging flames of a grand conflagration, seem small indeed.

Amount of Oxygen required Daily.

Whole population	1,000,000,000
Animals	2,000,000,000
Combustion and fermentation . .	1,000,000,000
Decay and other processes . .	<u>4,000,000,000</u>
Oxygen required daily	= 8,000,000,000 lbs.

"How utterly inconceivable are these numbers which measure the magnitude of Nature's processes, — eight thousand millions of pounds of oxygen consumed in a single day! When reduced to tons the number is equally beyond our grasp, for it corresponds to no less than 3,571,428 tons. If such be the daily requisition of this gas, will not the oxygen of the atmosphere be in time exhausted? It is not difficult to calculate approximately the whole amount of oxygen in the atmosphere. It is equal to

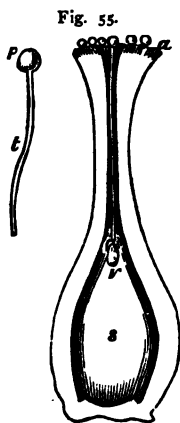
about 1,178,158 thousand millions of tons,—a supply which, at the present rate of consumption, would last about nine hundred thousand years.”

THE GROWTH OF PLANTS.

383. *The Embryo Plant in the Seed.*—The seed is formed in the flower, the essential parts of which are the *stamens* and the *pistil*. The *stamens* bear the *anthers*, and these contain the *pollen*. The pistil is in the centre of the flower. It encloses in its *ovary* the *ovules*, which, when ripened, become *seeds*.

In the ripe seed we find the *embryo*, which is a miniature plant with stem and leaves. How has this embryo been formed?

At a certain time a little cavity is formed in the centre of the ovule within the pistil. This cavity is called the



embryo sac, and is marked *s* in Figure 55. Within this sac, at its upper end, we see a minute body or *vesicle*, *v*. This is the first germ of the embryo; but in order that it may begin its development, it must be acted upon by the pollen. This we see in the form of small grains, *a*, resting on the top of the pistil. It has fallen from the anthers, and lodged here; and now it sends out a very fine and delicate tube, the *pollen-tube*, which pierces the tissue of the pistil, and extends itself until it reaches the vesicle, *v*. Its con-

tact with this microscopic particle of matter has the mysterious power of making it begin to *grow*, and thus form the embryo.

The vesicle is at first a single *cell*; that is, a membra-

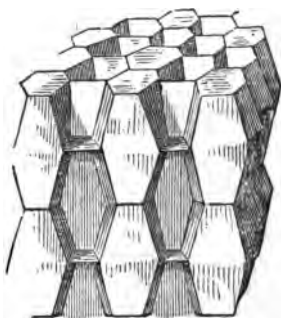
nous globule, filled with liquid, in which minute particles can sometimes be discerned. After it has been acted upon by the pollen-tube it enlarges somewhat, and a partition forms across its interior, dividing it into two cells. Each of these grows and divides in like manner, and thus a cluster of cells is formed. After a time the mass begins to take a definite shape. One end becomes the *radicle*, or the beginning of the *root* of the plant; and the other divides into two parts, which develop into the *cotyledons*, or *seed-leaves*. It is now a perfect embryo, a miniature plant, with root, stem, and leaves, but still shut up in the seed.

384. *The Plantlet.* — The growth of the plant in the seed and out of the seed is essentially the same process.

The same division and multiplication of cells continues, and all the parts of the plant are formed by the clustering or *aggregation* of these cells. The cells are too minute to be distinguished with the naked eye, but the microscope shows them in every portion of the plant.

Figure 56 shows a thin slice of a rootlet, cut crosswise and lengthwise, as it appears when

Fig. 56.

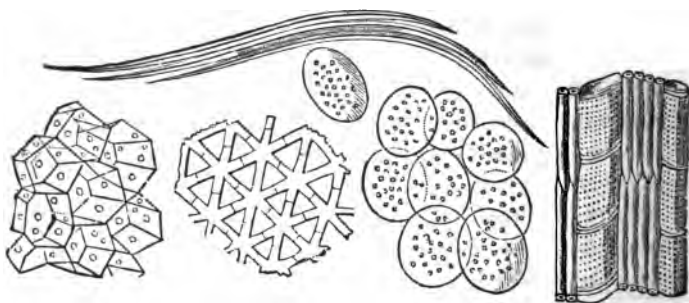


highly magnified. We see that the whole structure is *cellular*; that is, made up of cells crowded together. The natural shape of the cell is spherical; but when cells are clustered or crowded together they compress one another into the shape in which we see them in these figures. Where they are not thus squeezed, they are generally found to be spheres, more or less perfect. They vary in size from about the thirtieth to the thousandth of an inch in diameter.

At first the cells are all alike in shape and in texture ; but they are greatly modified in both respects in forming the varied tissues of the plant. They may be lengthened out into tubes, as in the fibres of cotton, which are single cells thus drawn out. The soft, thin membrane which encloses them may become hard and thick, as in the shell of a walnut or the tough wood of an oak. They may be closely crowded together, and nearly filled up with solid matter ; or they may be loosely interlaced, and form vessels to contain the vegetable juices. Their contents are as varied as their structure, and, seen through the transparent walls, give rise to all the manifold colors of leaf and flower and fruit.

Figure 57 (from Wood's "Class-book of Botany") shows a few of the varied forms which cells assume. At the

Fig. 57.



top we have wood-cells from the fibre of flax. Below are represented the many-sided cells of the pith of elder ; *stellate* (star-shaped) cells of the pith of the rush ; spherical cells of the houseleek ; and wood-cells of the oak.

385. *Organic Structure.* — This cellular structure is the characteristic of *organic* beings, that is, *plants* and *animals*, as distinguished from *inorganic* things, or *minerals* ; and hence it is called *organic* structure. The cell is "the

simplest form of organic life," whether vegetable or animal. Cells are the *units* of which the most complicated organic tissues are made up. They are essentially different, then, from the particles into which an inorganic or mineral substance may be divided. Each of these particles has all the properties of the mass from which it was separated, and if we divide it into yet smaller particles the same will be true of those ; and so on indefinitely. But if we cut a cell in two, the halves do not have the properties of the whole ; they are not smaller units, but the fragments of a unit.

386. *The Food of Plants.* — Plants get their food from the earth and the air, but much the greater part from the air. We know that there are plants which flourish in the most barren soil, or even upon the naked rock, and that some live and grow suspended in the air, and having no contact with the earth. Even those which demand a rich soil are indirectly indebted to the air for what they draw from the earth. The soil owes its fertility to the decomposition of organic matter ; and this organic matter was originally produced by plants which had no rich soil to draw from, but were dependent mainly upon the air.

The atmosphere, then, is the storehouse from which plants directly or indirectly obtain nearly all their food. The portion which is purely of earthy origin is always insignificant, and often it is nothing at all. In fact, plants give to the earth far more than they get from it. This is illustrated by the accumulation of vegetable organic matter in the soil wherever vegetation is undisturbed from year to year. In uncultivated fields and in primeval forests we often find a great depth of rich mould. The more rank and luxuriant the vegetation, the more rapidly this deposit increases, showing that the plants not only restore to the soil all that they have drawn from it, but are con-

tinually transferring fresh matter from the aerial store-houses to the earth.

But, while the soil is enriched by undisturbed vegetation, it is impoverished by agriculture. The farmer carries away the crop from the field, with all that it has taken from both the earth and the air. The land cannot yield in this way year after year, unless he follows the example of nature, and restores to the soil an equivalent for what he removes. This he can do by the use of *manure*.

387. *The Earthy Portion of the Plant.* — If we burn wood or any other vegetable substance, almost all of it is dissipated into air. But a little ashes will remain ; and these represent the earthy or *inorganic* portion of the plant. They consist mainly of alkaline chlorides, potash, soda, silica, metallic phosphates, calcic and magnesian carbonates, and ferric and manganic oxides. These are dissolved in the water which soaks through the soil and which is taken up by the roots of the plant. Much of the water is evaporated through the leaves, but the substances which it held in solution remain behind, and thus gradually accumulate in the tissues of the plant.

Since the plant must obtain from the soil the inorganic materials it needs, it is evident that it will flourish only in a soil containing those materials. This explains why certain plants thrive only in certain situations. A locality may be fertile for some species of vegetation and barren for others. The pines, which need little alkaline matter, will flourish in a sandy soil containing little alkali ; but the maples and elms, which require a good deal of potash, cannot live in such a soil.

We have said that the farmer who carries away the produce of the field with all that it has drawn from the soil must restore an equivalent in the form of *manure*, or the field will soon become impoverished.

"A medium crop of wheat takes from one acre of ground about 12 pounds; a crop of beans, about 20 pounds; and a crop of beets, about 11 pounds of phosphoric acid, besides a very large quantity of potash and soda. It is obvious that such a process tends continually to exhaust arable land of the mineral substances useful to vegetation which it contains, and that a time must come when, without supplies of such mineral matters, the land would become unproductive from their abstraction. . . . In the neighborhood of large and populous towns, for instance, where the interest of the farmer and market-gardener is to send the largest possible quantity of produce to market, consuming the least possible quantity on the spot, the want of saline principles in the soil would very soon be felt, were it not that for every wagon-load of greens and carrots, fruit and potatoes, corn and straw, that finds its way into the city, a wagon-load of dung, containing each and every one of these principles locked up in the several crops, is returned to the land, and proves enough, and often more than enough, to replace all that has been carried away from it." — BOUSSINGAULT.

This renewal of fertility is sometimes attained by letting the field lie *fallow*, or uncultivated, for one or more years. The inorganic materials of the soil are mainly furnished by the gradual disintegration of the *rocks*; and while the field lies fallow this process is going on, under the influence of the oxygen and carbonic acid of the air, aided by the rains and changes of temperature. In this way, fresh portions of the rocks or of their ruins are rendered soluble and thus fitted for the nourishment of plants.

An *alternation of crops* may answer the same purpose as letting the field lie fallow. For instance, wheat and potatoes may be raised on the ground in alternate years. The wheat requires a large amount of silica and alkaline

matter, while the potatoes take up no silica. The renewal of the soluble silica in the soil, therefore, goes on while the potatoes are growing, as it would if the field were fallow.

Some soils abound in silicates so readily decomposed that in every one or two years a sufficient supply for a crop of wheat becomes soluble. In Hungary there are large districts where wheat and tobacco have been raised alternately upon the same soil for centuries, the land never receiving back any of the mineral matter which is carried away with the crops. On the other hand, there are fields in which the amount of soluble silica required for a single crop of wheat is not separated from the insoluble masses in the soil in less than three or four years.

388. *The Organic Portion of the Plant.* — When we burned the vegetable matter, much the greater part of it passed off into the air. This was the *organic* portion of the plant. It was taken from the air, and the burning gave it back in the very form in which the plant found it there.

We have learned that all the vegetable tissues, however varied in their texture and consistency, are almost entirely made up of the same kind of cells. The substance of which these cells are made is called *cellulose*, or *woody fibre*; and it is a compound of carbon, hydrogen, and oxygen, — $C_{12}H_{20}O_{10}$. We have also learned that the plant contains small quantities of *albuminous* compounds (377), which, in addition to the elements just named, contain *nitrogen*. These four elements, then, are essential to the growth of the plant, and must be contained in its food.

389. *The Plant gets Hydrogen and Oxygen from Water.* — The hydrogen and the oxygen of the cellulose are obtained from the *water* which the plant takes in, not only through its roots, but through its leaves. It will be no-

ticed that water contains hydrogen and oxygen in the same proportions as cellulose does.

390. *The Plant gets Carbon from Carbonic Acid.* — We have learned that carbon is a solid, and insoluble in water. Even if it were reduced to the finest powder, and mixed with the water, it could not be taken up by the plant, since nothing but liquids and gases can pass through the walls of the cells. It must, then, be furnished to the plant in some liquid or gaseous compound, like the carbonic acid, which, as we have seen, is one of the gases mixed in the atmosphere.

Now, if a leafy plant be placed under a glass vessel and set in the sunshine, and a stream of carbonic acid be made to pass slowly over it, it is found that a part of the carbonic acid is removed, and replaced by oxygen. The plant absorbs the carbonic acid, decomposes it, retains the carbon, and exhales the oxygen.

We conclude, then, that it is from the carbonic acid in the atmosphere that plants get their carbon. In the leaves, under the influence of sunlight, the carbonic acid is decomposed, the carbon stored away in the plant, and the oxygen given back to the air.

Since carbonic acid is soluble in water, it is probable that plants also obtain a part of their carbon through the roots. Plants which live under water must get all their carbon from the gas dissolved in the water.

391. *The Plant gets Nitrogen from Ammonia.* — We know that there is ammonia in the atmosphere, and that this gas is very soluble in water. Hence it is washed out of the air by the rain, and, thus dissolved in water, is taken up by the roots of plants.

392. *The Growth of Plants is a Chemical Process carried on in the Leaf by the Sunlight.* — We have seen that the plant takes in water, carbonic acid, and ammonia; that it decomposes these substances; and that from their ele-

ments it elaborates all the organic compounds which enter into its own structure. The leaf is the laboratory in which this chemical process is conducted, and since it is only in sunshine or bright daylight that the work goes on, it is evident that the sunlight is the agency by which it is accomplished.

"The sun's rays, acting on the green parts of the leaf, give to them the power of absorbing water, carbonic acid, and ammonia, and of constructing from the materials thus obtained the woody fibre, starch, sugar, and other compounds of which the plant consists. We have analyzed the woody fibre, and we know that it is composed of charcoal and water. Nineteen ounces of wood contain nine ounces of charcoal and ten ounces of water. Moreover, the amount of charcoal required to make nineteen ounces of wood is contained in thirty-three ounces of carbonic acid. If, then, we add together thirty-three ounces of carbonic acid and ten ounces of water, and subtract from this sum twenty-four ounces of oxygen, we shall have just the composition of wood. This is what the sun's light accomplishes in the leaves of the plant. It decomposes the carbonic acid, and unites its carbon to the elements of water to form the wood." — COOKE.

What is here stated to be true of wood is equally true of other vegetable products. If in their production carbonic acid and water alone take part, we have such substances as woody fibre, starch, sugar, and gum ; and these make up nine tenths of all vegetable structures. If the ammonia is likewise employed in the process, we have *nitrogenized* products, like albumen and caseine.

The force which the sunbeam exerts in the decomposition of carbonic acid in the leaf is very remarkable, since it overcomes the intense affinity of oxygen for carbon.

"In order to decompose carbonic acid in our laboratories, we are obliged to resort to the most powerful chem-

ical agents, and to conduct the process in vessels composed of the most resisting materials, under all the violent manifestations of light and heat, and we then succeed in liberating the carbon only by shutting up the oxygen in a still stronger prison ; but under the quiet influences of the sunbeam, and in that most delicate of all structures, a vegetable cell, the chains which unite together the two elements fall off, and, while the solid carbon is retained to build up the organic structure, the oxygen is allowed to return to its home in the atmosphere. There is not in the whole range of chemistry a process more wonderful than this. We return to it again and again, with ever-increasing wonder and admiration, amazed at the apparent inefficiency of the means, and the stupendous magnitude of the result. When standing before a grand conflagration, witnessing the display of mighty energies there in action, and seeing the elements rushing into combination with a force which no human agency can withstand, does it seem as if any power could undo that work of destruction, and rebuild those beams and rafters which are disappearing in the flames? Yet in a few years they will be rebuilt. This mighty force will be overcome : not, however, as we might expect, amidst the convulsion of nature, or the clashing of the elements, but silently, in a delicate leaf waving in the sunshine." — COOKE.

393. *Plants purify the Air for the Respiration of Animals.*—We have learned (382) that by the various forms of combustion going on in nature, eight thousand millions of pounds of oxygen are daily removed from the atmosphere ; and that an immense amount of carbonic acid is pouring back into the air as one of the chief products of this combustion. The atmosphere, then, is continually losing the element which is essential to the support of animal life, and receiving in its place a gas which, even when largely diluted with air, is a deadly poison to animals.

But we have also learned that during the daytime plants are constantly drinking in this carbonic acid, and giving out an equal bulk of pure oxygen. They are thus purifying the air for the respiration of animals. They breathe in what animals breathe out, and breathe out what animals breathe in ; so that the air is kept in a fit state to sustain both forms of organic life.

394. *Plants prepare Food for Animals.* — We have seen that the plant draws its food directly from the earth and the air. It has the power of forming organic compounds out of inorganic matter. The animal, on the other hand, has no such power. It can elaborate its tissues only from organic matter, which it receives ready-made from the vegetable kingdom. It may get this matter either directly from the plant, as when it eats vegetable food, or indirectly, as when it eats animal food ; but in either case the origin is the same. By the process of digestion the organic compounds originally prepared by the plant are converted into bones, muscles, nerves, or whatever else enters into the structure of the animal. In this process, they do not undergo any radical change, but merely “become parts of more finely organized tissues.” We find in the blood albumen and caseine, having precisely the same composition as when prepared from potatoes, and the substance of the muscles does not differ essentially from the gluten of wheat-flour.

395. *The Relations of Plants and Animals to Each Other and to the Air.* — The plant, then, is a *producer* of organic materials ; the animal, a *consumer* of these materials. “While the plant is a true apparatus of reduction, the animal is a true apparatus of combustion, in which the substances derived from the vegetable are burned, and restored to the atmosphere in the form of carbonic acid, water, and ammonia, ready to be again absorbed by the plant and to repass through the phases of organic life:

Our bodies are furnaces, — furnaces continually burning, — whose fuel is our own flesh, and the smoke of whose fires is the food of the plant. . . .

“When the foundations of the globe were laid, there were collected in the atmosphere all the essential elements of organized beings. From this inexhaustible storehouse the plant absorbs water, carbonic acid, and ammonia, which were placed there for its use, and which have been made to serve as its nourishment and food. It is the special office of the plant to elaborate from these few mineral substances, and a small amount of earthy salts, all the materials of organized beings. The animal receives these crude materials already prepared, and builds with them its various tissues; but no sooner are the cell-walls finished, and the structure ready to discharge its vital functions, than it is consumed by almost the very act which gave it life. The carbonic acid, water, and ammonia are restored to the atmosphere, and the cycle is complete.” — COOKE.

SUMMARY OF THE CHEMISTRY OF THE ATMOSPHERE.

THE atmosphere contains oxygen, nitrogen, carbonic anhydride, and watery vapor, with traces of ammonia and nitric anhydride.

Ordinary combustion, decay, and respiration are chemical processes, differing from one another mainly in the rapidity and the completeness with which they take place.

The division of substances into *combustibles* and *supporters of combustion* is convenient, though merely conventional; since combustion consists in the chemical union

of two or more elements, and, in reality, one of the elements is just as combustible as another.

The present materials of the earth, being mainly compounds of hydrogen and carbon with oxygen, and of the metals with oxygen, chlorine, and sulphur, must be regarded as products of combustion.

The *rusting* of the metals is a process of slow combustion.

The products of combustion, decay, and respiration are chiefly *carbonic acid*, *water*, and *ammonia*.

The growth of plants is a chemical process, carried on in the leaf by the agency of the sunbeam. In growing, plants remove from the air carbonic acid, water, and ammonia. These compounds are broken up, — the oxygen in part given back to the air, and the other elements, with the remaining oxygen, rearranged so as to form the various vegetable compounds.

By removing carbonic anhydride from the air, and giving back oxygen, plants restore the equilibrium destroyed by the respiration of animals.

Animals derive all their food, directly or indirectly, from plants; while plants derive their food, directly or indirectly, from the air.

DESTRUCTIVE DISTILLATION AND ITS PRODUCTS.

396. *Combustion and Destructive Distillation.*—When vegetable substances are heated in closed vessels, so as to exclude the oxygen of the air, they are broken up into a number of compounds, which vary with the temperature to which they have been exposed. When vegetable matter burns or decays, these organic compounds, as we have seen, are broken up by the affinity of oxygen brought to bear upon them from without ; while in the other case they are broken up by the internal action of heat. In the first case new compounds are formed by the addition of new material ; in the second case, by subdivision, without any addition of new material. The first process is called *combustion* ; the second, *destructive distillation*.

397. *The Preparation of Charcoal.*—We have a very simple case of destructive distillation in the preparation of charcoal. This process may be illustrated by putting pieces of dry wood into a flask, closed with a cork, through which a glass tube passes. This tube passes into a cold glass bottle, and thence to a jar over water. Heat the flask, and the wood turns black. The jar fills with an inflammable gas. Hold a cold glass vessel over the flame of this gas, and moisture collects upon it, showing that water is a product of the burning of this gas. Carbonic acid also is found to be produced. This gas obtained from the wood must, therefore, be a compound of

hydrogen and carbon. A part of the carbon of the wood combines with oxygen to form carbonic acid ; another part with hydrogen, to form the inflammable gas ; while the greater part remains behind as a black solid. This black residue is charcoal, a form of carbon. If the heating is continued, and the gaseous products are conducted into a cold receiver, a liquid product is also obtained.

One way of preparing charcoal is to place billets of wood in an iron cylinder, which is closed air-tight and heated to dull redness. The volatile products are driven off and allowed to escape through a flue, and the solid charcoal remains behind.

A ruder method is practised in the country, where wood is plenty. A stake is set in level ground, and brushwood heaped around its base. Wood is then stacked round the stake, so as to form a mound some 20 or 30 feet in diameter. This mound is then covered, first with leaves or turf, and then with earth, leaving only a small opening at the bottom, through which the mound is set on fire. When the fire is well under way, the mound is covered more deeply and allowed to burn slowly out. This requires about a month. The burning of a part of the wood furnishes heat for charring the rest.

398. *The Products of the Distillation of Wood.* — When hard wood, as beech, is subjected to destructive distillation in a retort, and the volatile products are condensed in a suitable vessel, four principal classes of substances are formed : (1.) gases ; (2.) a watery fluid ; (3.) a dark resinous fluid ; (4.) charcoal.

(1.) This product is a mixture of inflammable gases, the most important of which are the two *hydrocarbons* (or compounds of hydrogen and carbon) *marsh-gas*, CH_4 , and *olefiant gas*, C_2H_4 .

(2.) This product is an acrid liquid, known as *pyroligneous acid*, or *wood vinegar*. From this acetic acid is obtained,

which is used in large quantities in the preparation of the acetates of iron, lead, and soda, which are much employed in dyeing and calico-printing.*

(3.) This product is *wood tar*, a thick liquid, insoluble in water, but soluble in alcohol. Its chief use formerly was for tarring and calking ships, but recently it has become an important source of both illuminating and lubricating oils. These oils will be more fully treated hereafter.

(4.) This product is the charcoal remaining in the retort. It is used chiefly as fuel and in reducing metallic ores.

399. *Methylic Alcohol*. — It was in wood-vinegar that methylic alcohol was first discovered by P. Taylor, in 1812: hence it is often called *wood-spirit*. Crude wood-vinegar probably contains about one per cent of methylic alcohol, which is separated from the bulk of the liquid by subjecting the whole to distillation, and collecting apart the first portions which pass over. The acid solution thus obtained is neutralized with slaked lime; and the clear liquid, separated from the oil which floats on the surface, and from the sediment at the bottom of the vessel, is again distilled. A volatile liquid is thus obtained, which burns like weak spirit; this may be strengthened by rectification, and rendered pure and anhydrous by careful distillation from quicklime.

Pure methylic alcohol is a colorless, thin liquid, very

* In the manufacture of acetic acid, the wood-vinegar is distilled, the first portion being collected apart for the preparation of wood-spirit. The remainder is saturated with lime, concentrated by evaporation, and mixed with solution of sodic sulphate; calcic sulphate is thereby precipitated, while the acetic acid is transferred to the soda. The filtered solution is evaporated to its crystallizing point; and the crystals are drained as much as possible from the dark, tarry mother-liquor, and deprived by heat of their combined water. The dry salt is then cautiously fused, by which the last portions of tar are decomposed or expelled; it is then redissolved in water, and recrystallized. Pure *sodic acetate*, thus obtained, readily yields acetic acid by distillation with sulphuric acid.

similar in smell and taste to ordinary or ethylic alcohol; crude wood-spirit, on the other hand, which contains many impurities, has an offensive odor and a nauseous, burning taste. Methylic alcohol boils at 66.6° , and has a density of 0.798 at 20° . When pure, it mixes in all proportions with water; it dissolves resins and volatile oils as freely as ethylic alcohol, and is often substituted for that alcohol in various processes in the arts, for which purpose it is prepared on a large scale. It may be burnt instead of ordinary spirit in lamps; the flame is pale-colored, like that of ethylic alcohol, and deposits no soot.

400. *Ingredients of Wood Tar.* — When beech-wood tar is distilled, a light oil passes over first, called *cypion*, or *wood naphtha*. It is now often sold under the name of *benzole*, and used as a burning-fluid, for removing oil-stains from clothes, and for countless other purposes. It burns with a brilliant white flame, free from smoke; but its extreme inflammability makes it a dangerous liquid for lamps. After this light oil has distilled over, a heavy oil follows. It contains various ingredients, the chief of which are *creosote* and *paraffine*.

401. *Creosote.* — This is an oily, colorless liquid, with a peculiar smoky odor. It has remarkable *antiseptic* (or preservative) properties. A piece of flesh steeped in a very dilute solution of it dries up into a mummy-like substance, which refuses to decay. Meat, as tongues or hams, may be almost instantly *cured* by dipping it into a solution containing one part of creosote to 100 parts of water or brine. It is this substance which imparts to wood-smoke its property of preserving meat. It is a compound of carbon, hydrogen, and oxygen. It is quite neutral to test-paper. Its density is 1.037, and its boiling-point about 203° . It takes fire with difficulty, and then burns with a smoky light. When quite pure, it is not altered by exposure to the air. 100 parts of cold water take up about

part of creosote ; at a high temperature rather more is dissolved, and the hot solution abandons a portion on cooling. The creosote itself absorbs water also to a considerable extent. In acetic acid it dissolves in much larger quantity, and it mixes with alcohol and ether in all proportions.

402. *Paraffine*.—This is a pearly-white, tasteless, and odorless solid. The most corrosive acids and alkalies have no effect upon it. Hence its name, from *parum*, little, and *affinis*, from which *affinity* is derived. It is also called *cerotene*.

It burns with a bright white flame, without smoke. It is now much employed as a material for candles, which for purity and lustre are not surpassed by even the best and most costly wax-candles.

Unsized paper, after having been soaked in paraffine, may be kept for weeks in concentrated sulphuric acid without undergoing the slightest alteration. Hence it is an excellent coating for the labels of bottles in which acids are kept.

403. *Asphalt*.—Asphalt, or pitch, is the residue left after distilling tar. It is used for varnishes, and as a material for making lamp-black.

404. *Slow Destructive Distillation*.—When vegetable substances decay with a partial or complete exclusion of air, we have a kind of *slow* destructive distillation. Hydrocarbon gases, which in some places escape from the earth in large quantities, are one of the products of this process ; the well-known coal-oils are another ; and coal is a third. The gas obtained by stirring the mud in marshes and at the bottom of stagnant pools is formed in this way, and is made up chiefly of marsh-gas, CH_4 , and carbonic acid, CO_2 .

405. *The Formation of Mineral Coal*.—In tropical swamps where vegetation is rank, vast masses of vegetable matter

accumulate, and gradually decay under water. In some cases the land at the bottom of these swamps is slowly sinking, and the bed of peat, as it sinks with it, becomes covered with mud and sand, which numerous streams are washing down upon it. This goes on, year after year and century after century, until the bed is buried hundreds of feet beneath the surface. The vegetable matter thus sunk in the earth, and subjected to enormous pressure, gradually undergoes a process of internal combustion similar to that which takes place under water. In many cases the decomposition is hastened by the agency of the internal heat of the earth. It is probable that the vast beds of coal found in various parts of the earth have been thus formed. All this coal is the remains of an ancient vegetation, and it undoubtedly required millions upon millions of years to complete its conversion into coal.*

456. *Hard and Soft Coals.* — The mineral coals may be conveniently divided into hard, or *anthracite*, and soft, or *bituminous* coal, and there are several varieties of each.

The main differences between the two are these: hard

* The vegetable origin of coal has been placed beyond doubt by microscopic research; vegetable structure can be thus detected even in the most massive and perfect varieties of coal when cut into thin slices. In coal of inferior quality, much mixed with earthy matter, it is evident to the eye. The leaves of ferns, reeds, and other succulent plants, more or less resembling those of the tropics, are found in a compressed state between the layers of shale or slaty clay, preserved in the most beautiful manner, but entirely converted into bituminous coal. The coal-mines of Europe, and particularly those of our own country, furnish an almost complete fossil flora, — a history of many of the now lost species which once adorned the surface of the earth.

In *lignite* or *brown coal* the woody structure is much more obvious. Beds of this material are found in very many of the newer strata, above the true coal, to which they are consequently posterior. As an article of fuel, brown coal is of comparatively small value; it resembles peat, giving but little flame, and emitting a disagreeable pungent smell.

It, used for making black ornaments, is a variety of lignite.

coal is almost pure carbon, while soft coal contains also considerable hydrogen and some oxygen; hard coal still retains the cellular structure of the wood, which is clearly seen under the microscope, while in soft coal this cellular structure is almost entirely wanting; hard coal burns without flame, soft coal with flame.

407. *Products of the Distillation of Bituminous Coal.*—

The products obtained by the destructive distillation of coal are still more numerous than those obtained from wood. Wood, containing much oxygen and comparatively little nitrogen, furnishes compounds which contain much acetic acid and little ammonia, and which, therefore, have an *acid* reaction. Coal, on the other hand, contains much nitrogen and little oxygen, and gives products rich in ammonia, and having consequently an *alkaline* reaction.

When coal is distilled at high temperatures, an abundance of an inflammable gas is obtained, and also a large amount of liquid products, which are then called *tars*.

When coal is distilled at a low temperature, but little gas is obtained, and the liquid products are then called *oils*.

408. *The Composition of Coal-Tar.*—Coal-tar has been found to contain three classes of substances:—

- (1.) Acid oils, soluble in alkalis.
- (2.) Alkaline oils, soluble in acids.
- (3.) Neutral oils, not affected by alkalis and some acids.

409. *Carbolic Acid (Phenylic Alcohol, Phenol).*—The most important and abundant ingredient in the acid oils just mentioned is *carbolic acid*, C_6H_5O . When pure, it forms long, colorless, prismatic needles, which melt at 35° to an oily liquid, boiling at 180° , and greatly resembling creosote in many particulars, having a very penetrating odor and burning taste, and attacking the skin of the lips. Its sp. gr. is 1.065. It is slightly soluble in water, freely in alcohol and ether, and has no acid reaction to test-paper. The crystals absorb moisture with avidity, and liquefy. It is a

powerful antiseptic, preserving meat and other animal substances from decomposition, and even removing the fetid odor from them after they have begun to putrefy. It is one of the most valuable *disinfectants* known, and is extensively used for that purpose. It is also largely employed as a permanent dye-stuff for silk and woollen goods. This dye-stuff is prepared by heating carbolic acid moderately with nitric acid. This mixture is called *picric acid*. On evaporating this liquid, yellow scaly crystals are obtained. Like all the tar colors, its dyeing qualities, when in solution, are most intense. Silk and woollen goods put into the solution, even when cold, assume a rich yellow color, far surpassing that obtained from other dyes.

410. *Aniline*. — The most important ingredients of the alkaline oils obtained from coal-tar are ammonia and *aniline*, C_6H_5N .

Aniline is an oily substance which, when acted upon by compounds which readily part with oxygen, furnishes a complete series of the most brilliant dyes. The preparation of these rich dyes from aniline is one of the most interesting discoveries of modern times, and has caused almost a revolution in the arts of dyeing and calico-printing. It is still more surprising when we consider that these brilliant colors are obtained from what was until recently a disagreeable waste product of the gas-works. When first prepared, they were worth their weight in gold; now they can be bought at a comparatively moderate price.*

* *Aniline purple*, or *mauve*, is a brittle substance, having a beautiful bronze-colored surface; it is difficultly soluble in cold water, although it imparts a deep purple color to that liquid; it is more soluble in hot water, very soluble in alcohol, nearly insoluble in ether and hydrocarbons; it dissolves in concentrated acetic acid, from which it crystallizes. Mauve is the sulphate of a base called *mauveine*, having the composition

411. *The Neutral Oils obtained from Coal-Tar.* — The neutral oils are the *coal-oils* proper. They contain a great variety of compounds, both liquid and solid, the latter being held in solution. Of the liquids, *benzol*, *toluol*, and *cumol* are the most important; and of the solids, *paraffine* and *naphthaline*.

412. *Benzol (Benzole or Benzene).* — This substance, C_6H_6 , is now prepared in immense quantities for the manufacture of aniline.

Pure benzol is a thin, limpid, colorless, strongly refracting liquid, having a peculiar ethereal odor. It has a den-

sity $C_{17}H_{15}N_3$, and capable of forming numerous crystalline salts with acids.

Aniline red, or *rosaniline*, $C_{20}H_{15}N_3$, occurs more or less pure in commerce under the names *roseine*, *fuchsine*, *magenta*, *azaline*, etc. A red color had been observed at different times in experimenting with aniline, more especially when that substance was digested with Dutch liquid. The red coloring matter, though still impure, was first obtained in a separate state from the product formed by digesting aniline with carbonic tetrachloride at 150° . It was M. Verguin who first prepared it upon a large scale by the action of stannic chloride upon aniline. Since that time it has been produced by the action of mercuric salts, arsenic acid, and many other oxidizing agents, upon aniline.

The aniline reds of commerce are saline compounds, more or less pure, of rosaniline with one equivalent of acid. The acetate, which is chiefly found in commerce in England, has been prepared by Mr. Nicholson in splendid crystals of very considerable dimensions, having the composition $C_{20}H_{15}N_3 \cdot C_2H_3O_2$. In France the chloride is chiefly employed; its formula is $C_{20}H_{15}N_3 \cdot HCl$.

M. Girard and De Laire obtained *aniline blue* by digesting rosaniline with an excess of aniline. Together with aniline blue, which is the principal product of the reaction, several other coloring matters (violet and green) and indifferent substances are formed, considerable quantities of ammonia being invariably evolved. The blue coloring matter consists of $C_{20}H_{15}(C_6H_5)_3N_3$. Dr. Hofmann has obtained an *aniline violet*, having the composition $C_{20}H_{15}(C_2H_5)_3N_3$.

A yellow coloring matter, called *chrysaniline*, contains $C_{20}H_{17}N_3$; it is also a well-defined base, forming two series of salts.

sity of 0.885 at 15.5° ; boils at 82° , and solidifies at 3° to a white crystalline mass. It is nearly insoluble in water, but mixes with alcohol and ether. It dissolves iodine, sulphur, and phosphorus, and a large number of organic substances, — fats and resins, for example, — which are insoluble, or very sparingly soluble, in water and alcohol: hence its use in many chemical preparations, and for removing grease-spots from articles of dress.

413. *Nitrobenzol*. — Benzol dissolves readily in strong nitric acid, and on adding water to the solution, *nitrobenzol* or *nitrobenzene*, $C_6H_5(NO_2)$, separates. It is a yellowish liquid, smelling like bitter almonds, and hence used in perfumery. It is known commercially as *artificial oil of almonds*. By reducing agents it is converted into *aniline*.

414. *Toluol and Cumol*. — *Toluol* (*toluene*), C_7H_8 , and *cumol* (*cumene*), C_9H_{10} , are the chief ingredients of the well-known illuminating or lamp oils obtained from coal.

415. *Naphthaline*. — Naphthaline, $C_{10}H_8$, is a beautiful, pearly-white solid. It forms large, colorless, brilliant, crystalline plates, exhaling a faint and peculiar odor, which has been compared to that of the narcissus. Naphthaline melts at 80° to a clear, colorless liquid, which crystallizes on cooling; it boils at 212° , and evolves a vapor whose density is 4.528. When strongly heated in the air it inflames, and burns with a red and very smoky light. It is insoluble in cold water, but soluble to a slight degree at the boiling temperature; alcohol and ether dissolve it easily.*

* *Anthracene or paranaphthaline*, $C_{14}H_{10}$, is produced in the dry distillation of coal, bituminous shale, and wood, and is contained in the last heavy and semifluid portions of the tar. A commercial product of this kind, used as a lubricator for machinery, is yellow, soft, somewhat like palm-oil, and contains anthracene, together with several other hydrocarbons. To obtain pure anthracene, the crude commercial product is distilled from an iron retort, the first and last portions of the distillate being rejected, and the intermediate portion crystallized either from alcohol or from coal-oils boiling between 100° and 120° .

Brilliant red and blue colors, rivalling those prepared from aniline, have lately been obtained from this solid.

When vegetable matter is distilled at a high temperature, benzol and naphthaline are formed in great abundance, with but small quantities of toluol, cumol, and paraffine. When, on the other hand, the distillation is conducted at a low temperature, toluol, cumol, and paraffine are formed in large quantities, with but little benzol and naphthaline.

COAL-OILS AND ALLIED SUBSTANCES.

416. At the beginning of the present century the means of lighting our dwellings consisted, in the main, of poor tallow-candles and dim and dirty oil-lamps. On the continent of Europe whale-oil and other animal oils were costly, and there, consequently, resort was had to natural tar and bituminous slate, in order to obtain illuminating oils. For more than twenty years past lamp-oils have been extensively prepared from wood, resin, and bituminous matter.

In Great Britain and in this country the manufacture of coal-oils is of much more recent growth, because the extensive whale-fisheries supplied all the wants of the market.

The manufacture of coal-oil was introduced into this country in 1853, and was at first confined to those districts where bituminous coal could be mined at a cheap rate.

Soon after this manufacture was established in this country, and after the value of coal-oils came to be fully recognized, attention was drawn to *petroleum*, or rock-oil, as a ready means of supplying these oils cheaply. On examination, this oil was found to be analogous, in its composition and its properties, to that distilled from soft coal and other bituminous materials.

417. *The Origin of Petroleum.* — All scientific men are agreed that the petroleum found in the earth results from the decomposition of organic matter, and nearly all are agreed that it results mainly from the decomposition of *vegetable* matter. It is, however, a disputed point, whether it results from the original decomposition of the vegetable substances, or from the action of the internal heat of the earth on the bituminous coal at a subsequent period.

It is probable that the petroleum now found in the earth is the product both of the original decomposition and of subsequent distillation. Petroleum is, however, rarely found in contact with bituminous strata of any kind. It is more often found in fissures in sand rocks, — rocks in which no oil could ever have been generated, since whatever organic matter they might have contained was too much exposed to atmospheric oxygen to admit of its being *bituminized*, or made bituminous. It is not only impossible that the oil could have originated in these sand rocks, or in the sandy shales which underlie them in the Oil Region in Western Pennsylvania, but it is most probable that the oil ascended from still lower rocks in the form of vapor, which condensed in the cavities above. Since, then, petroleum is seldom found where it originated, but ordinarily in cavities of rocks higher up, it seems probable that it is *mainly* the product of distillation.*

The chemical conditions essential to the generation of oil have evidently existed over a very wide area; but the oil is found only where fissures exist in the rocks. These fissures serve two purposes: one to give space for the formation and expansion of the hydrocarbon vapor, the

* Reichenbach, by distilling with water about 100 lbs. of pit-coal, obtained nearly 2 ounces of an oily liquid, exactly resembling the natural naphtha of Amiano, in Italy. The manufacture of such products (paraffine oils) by distilling Boghead and other kinds of coal at a low red heat, is now conducted on a very large scale.

other to furnish receptacles for the condensed oils. These fissures must connect with the sources of the oil. If they have any outlets at the surface of the earth, by which the more volatile portions of the oil may escape as gas, the oil within them becomes thicker and heavier. Hence, as a general rule, the oil found near the surface is heavy, the cavities containing it being likely to have outlets. It may, of course, happen that a deeply seated fissure has such an outlet.

418. *How Petroleum is obtained.* — The oil is obtained by piercing one of these cavities by a well. It often happens that the upper part of the cavity is filled with pent-up uncondensable gases. In this case, if the well happens to pierce the lower part of the cavity, the expansive force of the confined gases will drive the oil from the well in a continuous stream. Oil is often forced from a new well with such velocity, that it rises in a jet a hundred feet high.

It sometimes happens that the lower part of the cavity is filled with brine, upon which the oil floats. If, in this case, the well pierces the lower part of the cavity, brine is the first product. After a time the salt-well may change to an oil-well.

419. *Localities where Rock-Oils are found.* — On the northwest side of the Caspian Sea, near Baku, where beds of marl are found saturated with naphtha, wells are sunk to the depth of about 30 feet, in which naphtha and water collect, and are easily separated. In some parts of this district so much combustible gas or vapor rises from the ground that, when set on fire, it continues burning, and even affords heat for economical purposes. A large quantity of an impure variety of petroleum comes from the Birman territory in the East Indies: the country consists of sandy clay, resting on a series of alternate strata of sandstone and shale. Beneath these occurs a bed of pale-blue shale loaded with petroleum, which lies immediately on

coal. A petroleum-spring exists at Colebrook Dale, in Shropshire, and immense quantities are found in Canada, Pennsylvania, and other parts of North America. The sea near the Cape de Verd Islands has been seen covered with a film of rock-oil. Fine specimens of naphtha are furnished by Italy, where it occurs in several places.

420. *Properties of the Rock-Oils.* — The term *naphtha* is given to the thinner and purer varieties of rock-oil, which are sometimes nearly colorless; the darker and more viscid liquids bear the name of *petroleum*. The variations of color and consistence in different specimens of rock-oil depend in great measure upon the presence of pitchy and fatty substances dissolved in the more fluid oil.

The boiling-point of rock-oil varies from about 80° to 326° . A thermometer inserted into a retort in which the oil is undergoing distillation never shows for any length of time a constant temperature; hence it is inferred to be a mixture of several different substances. Neither do the different varieties of naphtha give similar results on analysis; they are all, however, hydrocarbons.

421. *Bitumens.* — The true bitumens are destitute of organic structure; they appear to have arisen from coal or lignite by the action of subterranean heat, and very closely resemble some of the products yielded by the destructive distillation of those bodies. They are very numerous, and have yet been but imperfectly studied.

1. *Mineral pitch, or compact bitumen, the asphaltum* of some authors, occurs abundantly in many parts of the world, — as in the neighborhood of the Dead Sea in Judæa; in Trinidad, in the famous *pitch lake*; and elsewhere. It generally resembles in aspect common pitch, being a little heavier than water, easily melted, very inflammable, and burning with a red, smoky flame. It consists principally of a substance, called by Boussingault *asphaltene*, composed of $C_{20}H_{20}O_2$.

2. *Mineral tar* seems to be essentially a solution of asphaltene in an oily fluid called *petrolene*. This liquid has a pale-yellow color and peculiar odor; it is lighter than water, and very combustible, and has a high boiling-point. It has the same composition as the oils of turpentine and lemon-peel, — namely, $C_{10}H_{16}$. Asphaltene contains, consequently, the elements of petrolene, together with a quantity of oxygen, and probably arises from the oxidation of that substance.

3. *Elastic bitumen*, or *mineral caoutchouc*, has been found in only three places, — in a lead-mine at Castleton, in Derbyshire; at Montrelais, in France; and in the State of Massachusetts. In the two latter localities it occurs in the coal series. It is fusible, and in many respects resembles the other bitumens.

COAL-GAS.

422. *The Manufacture of Coal-Gas.* — The idea of turning hydrocarbon gases to the practical purposes of illumination occurred at about the same time to Murdock, in England, and Lebon, in France. This was in 1790; but for a long time there was a strong popular feeling against the new light. In England it was not until 1812 that Parliament consented to charter a company for its manufacture. Even then the enterprise was looked upon as so visionary, that the act of incorporation was said to be granted in order to make a great experiment of a plan of such extraordinary novelty. In December, 1813, Westminster Bridge was first lighted with gas. From this time gas-lighting made the most rapid progress in England; and now the consumption of gas in London alone amounts to more than seven billions of cubic feet annually. To make this gas, eight hundred thousand tons of coal are required; while the length of the main pipes in

the streets of the city is more than two thousand miles. Paris was first lighted with gas in 1820. There, as in England, strong prejudices had to be overcome.

The most essential parts of the apparatus used in the making of coal-gas are represented in Figure 58.

Of course, it is only soft or bituminous coal that can be used for making gas. This coal is distilled in long iron retorts, seen at the left of the figure. When charged with coal these retorts are closed air-tight. They are then heated to a very high temperature by the furnaces beneath.

The gaseous and volatile compounds formed by the distillation of the coal pass up through pipes (one of which may be seen leading from each retort) into a long horizontal pipe, *M*, called the *hydraulic main*. This is half full of water, into which the pipes from the retorts dip. The gas readily escapes from the pipes by bubbling up through the water; but, of course, it cannot return through the water.

The gas is carried from the hydraulic main through a pipe into a tank, *T*, called the *tar cistern*. By this time the more condensible gases have become liquid, and collect in the smaller vessel into which the pipe passes, and from which they overflow into the larger tank. From the latter they are drawn off at intervals. These condensed products are coal-tar and a liquid highly charged with ammonia, called *ammoniacal liquor*.

The uncondensed gases pass on through the series of upright pipes at *C*, called the *condenser*. Here they become still further cooled, and all the remaining condensable gases are reduced to the liquid state.

After leaving the condenser the gas still contains, besides the compounds fit for illuminating purposes, the noxious compounds carbonic anhydride and hydric sulphide. These are removed in the *purifier*, *P*. This is a chamber

with several perforated shelves, which are covered with slaked lime. In passing over this lime the carbonic an-

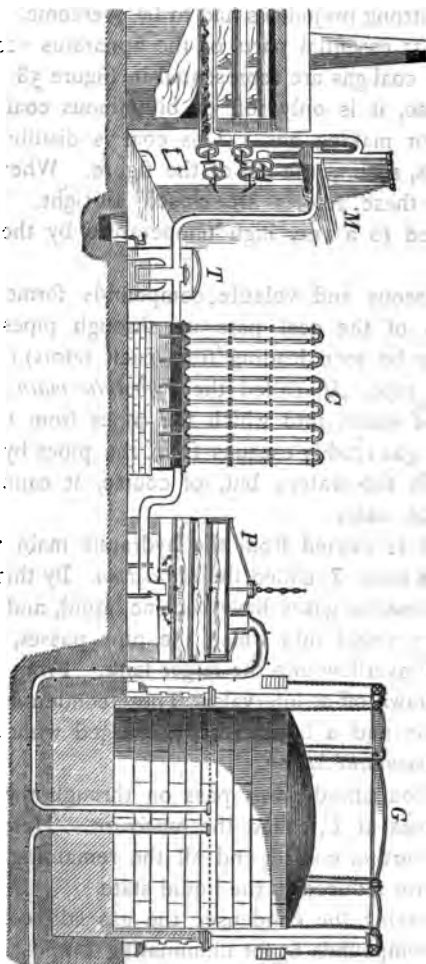


Fig. 58.

hydride and hydric sulphide are absorbed, while the purified gas passes along into the *gasometer*, *G*. This consists

of a large sheet-iron bell-jar, which dips into a cistern of water. The latter is deep enough to allow the bell to be completely submerged, and filled with water. The bell is counterpoised with weights, and rises as the gas enters it.

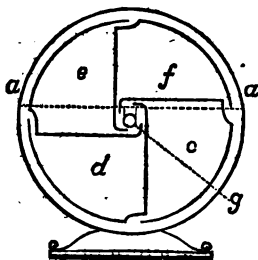
From the gasometer the gas passes out, by the pipe at the right, into the streets and houses of the city.*

ILLUMINATION.

423. *Nature of Flame.* — We know that coal-gas burns with flame, while the solid carbon burns without flame. All combustible gases burn with flame.

* The gas received into each house is made to pass through a self-acting instrument, called a *gas-meter*, by which it is measured. One of the most common forms of the instrument (Figure 59) consists of an

Fig. 59.



outer case, *a a*, filled with water up to the horizontal dotted line, and, within it, a revolving drum, divided into four compartments, *c, d, e, f*, by as many bent partitions. The bending of the partitions forms a central space, *g*, and thus the gas can pass from one division into the next. The gas enters at the back of the outer case by a pipe which passes into the central space, where it rises a little above the surface of the water. As one compartment gets filled with gas, it becomes lighter and rises,

thereby causing the drum to perform a fourth of a revolution. In the figure, the gas is passing into the division *c*. As this fills and rises, *d* comes into the same position; then *e*; and then *f*, which, being filled, and rising, completes one revolution. It will be seen that, as each compartment rises above the level of the water, the gas contained in it can pass out through a slit in the rim of the drum into the outer case, and from the top of the case a pipe conveys it to the burners. Thus, while one compartment is losing its gas, another one is filling, and so on. The revolution of the drum gives motion to a train of wheels, which in turn move the hands on dial-plates, and thus register the number of cubic feet of gas that have passed through the meter.

We have seen that wood, when heated in a closed tube, gives off an inflammable gas; and the same is true of wax or tallow heated in the same way. Every *solid* which appears to burn with flame can thus be converted into an inflammable gas by means of heat. When these solids begin to burn, the heat developed is sufficient to generate this inflammable gas. It is this gas, and not the solid, which burns with flame. Flame, then, is gas burning.

424. *A Solid, or a Dense Vapor, and Heat, are necessary to Illumination.* — The oxy-hydrogen flame is intensely hot, but gives scarcely any light. If, however, a cylinder of lime be held in the flame, we get the brilliant *calcium* light (120). When phosphorus is burned in oxygen (119) the hot dense vapor of phosphoric anhydride (155) is dazzlingly bright.

In every luminous flame we have a *solid*, or a *dense vapor*, or both, *intensely heated*. (See Appendix, III.)

425. *The Burning of Coal-Gas.* — Illuminating gas, as we have seen, is a compound of carbon and hydrogen. If we hold a cold glass rod in a gas-flame, it becomes blackened with soot, showing that there is free carbon in the flame. We therefore conclude that the hydrogen of the gas combines with the atmospheric oxygen first. In doing so it develops great heat.

It has been observed that, in the manufacture of charcoal, the delicate cells of the wood are preserved intact; showing that the carbon, at the high temperature to which it is exposed in the process, has no disposition to melt. Carbon is equally infusible in the highest temperature that we can produce. Its fixedness in the solid state is its most marked characteristic.

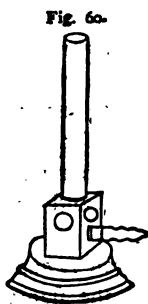
When the hydrogen of coal-gas combines with the oxygen of the air, the carbon is set free in a solid state. As the hydrogen consumes all the oxygen in the nearest layer of air, the carbon must delay a moment in the flame before it

can get at oxygen to unite with. This finely-divided solid thus becomes heated white-hot, and gives out light. This condition lasts but an instant. The next instant the carbon combines with atmospheric oxygen, and passes off as a colorless gas. As fast, however, as the carbon is consumed, a fresh supply is set free, and thus the light is constantly kept up.

The value, then, of coal-gas for illumination depends upon a most delicate adjustment of affinities.

Were the affinity of carbon for oxygen a little stronger than it now is, the carbon would burn at the same time with the hydrogen, and there would be no light in the flame. On the other hand, were the affinity of carbon for oxygen less than it is, the carbon would not burn at all, but after developing light would pass away from the flame in the form of soot.

426. *Bunsen's Lamp*. — The fact that carbon must remain an instant in the flame in the solid state to develop light, is illustrated by Bunsen's burner. It is shown in Figure 60,



and consists of a brass tube, near the bottom of which are four round holes, through which the air can pass into the tube. A second tube opens into the inside of the brass tube from the bottom, just on a level with these holes. The coal-gas passes into the larger tube through this second tube. The air passes in through the holes at the same time, and the two gases become intimately mixed before they reach the top of the tube. Upon lighting the mixture as it escapes from the tube, it burns with scarcely any light, but a good deal of heat. If the holes at the bottom of the tube are closed, the gas burns with the ordinary luminous flame. In the first case, there is an excess of oxygen mixed with the coal-gas, so that there is enough to combine with the carbon as

soon as it is set free, before it becomes sufficiently heated to develop light. In the second case, the carbon cannot get at the oxygen to combine with it, until it has passed through the burning layer of hydrogen, and thus become intensely heated.

427. *The Best Shape for a Gas-Flame.* — From what has already been said, it is evident that the light of the flame is developed only at the surface, in the burning layer of hydrogen. The ordinary gas-burner is so made that the flame will be flat, in order that it may have as much surface as possible. The greater the surface, the greater the light developed.

428. *The Argand Burner.* — A sheet of paper will evidently present to the air just as much surface when it is bent round till the two edges meet, as when it is flat; while in the second case it is in a more compact form. So the ordinary gas-flame will present just as much surface, if its edges are bent round till they meet. In the Argand burner, this cylindrical form is given to the flame, by supplying the gas through a circle of small holes in a hollow brass ring. A current of air passes up through this ring, furnishing oxygen to the inner surface of the flame.

429. *The Bude Light.* — If the interior of the ring of an Argand burner be closed, the flame becomes of a dull red color. Since no oxygen is supplied to the inner surface of the flame, the combustion is imperfect, and develops but a low degree of heat.

If, on the other hand, a stream of pure oxygen is supplied to the interior of the cylindrical flame, the flame diminishes in size, but the light becomes very intense, and of a pure white color. The increased supply of oxygen increases the energy of the combustion of the hydrogen, and the intensity of the heat developed by it. In the first case the carbon is heated only to a dull redness, while in the second case it is raised to a full white heat.

430. *A Burning Candle is a miniature Gas-Factory.*—

We have already seen that wax or tallow, when heated in a flask, is converted into an inflammable gas. This gas in burning produces water and carbonic acid; hence it must contain hydrogen and carbon, which are the main ingredients of coal-gas. This gas is in fact identical with coal-gas. The heat of the burning match converts some of the wax of the candle into inflammable gas. This gas takes fire, and in burning develops sufficient heat to convert more of the wax into gas, which is consumed as fast as formed.

431. *The Flame of a Candle consists of three distinct Parts.*

— In the flame of a candle there are three distinct parts :

(1.) the dark central zone, or supply of unburnt gas surrounding the wick ; (2.) the luminous zone, or area of incomplete combustion ; and (3.) the non-luminous zone, or area of complete combustion. If we put one end of a small glass tube (see Figure 61) into the dark central zone, the unburnt gas will pass up the tube, and may be ignited at the other end. In the luminous part of the flame, as we have seen in the case of the gas-flame (425), the gas is not completely burnt, and carbon is separated in the solid state ; and it is this carbon heated white-hot which renders the flame luminous. In the outer zone the supply of oxygen is greater, all the carbon is at once burnt to carbonic acid, and the flame here becomes non-luminous.

Fig. 61.



432. *The Blowpipe Flame consists of two Parts.*—A blowpipe is an instrument for sending a jet of air or oxygen into a flame, in order to make its heat more intense. In this way a common flame is converted into a kind of fur-

nace, capable of fusing or raising to a high temperature any small body exposed to its action. The blowpipe, in one form or another, is very extensively used in chemistry and the arts.

The common mouth-blowpipe is merely a bent brass tube, tapering to a very fine jet.

The blowpipe flame consists of two distinct parts (see

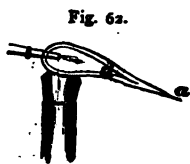


Figure 62): (1.) the *oxidizing* flame, *a*, where there is excess of oxygen; and (2.) the *reducing* flame, *d*, where there is excess of carbon. These correspond to the outer and middle zones of the candle-flame.

If the end of a copper wire be introduced into the oxidizing part of the flame, it at once combines with the heated oxygen, and becomes coated with oxide. If now it be put into the *reducing* flame, the heated carbon at once takes the oxygen away, and reduces it to the metallic state.

SUMMARY OF DESTRUCTIVE DISTILLATION AND OF ILLUMINATION.

Vegetable compounds may be broken up by means of heat into a great number of substances, which vary with the temperature to which the compounds are exposed.

This process is called *destructive distillation*.

The preparation of charcoal is one of the simplest cases of destructive distillation. In this case the wood is decomposed into carbon and a number of volatile compounds.

When these volatile products are cooled and condensed, they give rise to three classes of compounds: (1.) per-

manent gases ; (2.) a watery fluid ; (3.) a dark resinous fluid.

(1.) The permanent gases are chiefly two *hydrocarbons*, or compounds of carbon and hydrogen, called *marsh-gas*, CH_4 , and *olefiant gas*, C_2H_4 .

(2.) The chief ingredient of the watery fluid is *pyroligneous acid*, or *wood-vinegar*, a compound of carbon, hydrogen, and oxygen, from which acetic acid is prepared.

(3.) The dark liquid is *wood-tar*, which contains a variety of substances, mostly compounds of carbon and hydrogen.

The most important of these ingredients of wood-tar are *wood naphtha*, *creosote*, *paraffine*, and *asphalt*.

Mineral coal has probably been formed by the gradual decomposition of vegetable substances buried in the earth, and thus excluded from the air. It is probable that this decomposition has, in many cases, been hastened by the internal heat of the earth.

When the volatile products were allowed to escape freely, *anthracite* coal was formed. When these products could not escape at the time of their formation, *cannel* and other varieties of *bituminous* coal were formed.

The volatile products often escaped into large cavities in the rocks, and on condensing gave rise to the celebrated *rock-oil*, or *petroleum*.

In some cases this oil may have been formed by the gradual decomposition of the vegetable substances at a temperature too low for its conversion into vapor, and may afterwards have been distilled by the internal heat of the earth.

The products of the destructive distillation of bituminous coal are even more numerous than those of the distillation of wood. These products are not so rich in compounds containing *oxygen*, such as acetic acid and creosote ; but they are richer in compounds containing *nitrogen*, such as ammonia and aniline.

When the coal is distilled at a high temperature, a large amount of gas is obtained, and the liquid products are then called *tars*. When the coal is distilled at a low temperature, only a small amount of gas is obtained, and the liquid products are called *oils*.

When the gas obtained by the distillation of coal is purified, it forms the well-known *illuminating-gas*.

The most important ingredients of *coal tar* are *carbolic acid*, *ammonia*, *aniline*, *benzol*, *toluol*, *cumol*, *paraffine*, and *naphthaline*.

The celebrated *aniline colors* are prepared chiefly from benzol.

When the coal is distilled at a high temperature, benzol and naphthaline are formed in much greater quantities than when it is distilled at a low temperature; while in the latter case toluol, cumol, and paraffine are more abundant products than in the former.

Solids burn without flame. Only gases burn with flame.

Solids that appear to burn with flame are first converted into a gas by heat, and this gas burns with flame.

The conditions essential to illumination are the presence of a *solid*, or a *dense vapor*, and intense *heat*.

The illuminating gases are all *hydrocarbons*, or compounds of hydrogen and carbon.

The hydrogen has the stronger affinity for oxygen, and burns first. The carbon is set free in a solid state, and, delaying for an instant in the intense heat of the flame, becomes luminous. It then combines with oxygen, forming an invisible gas, carbonic acid.

The light of the flame is increased by increasing the surface of the flame. Hence the ordinary gas flame is made flat, or, as in the case of the Argand burner, cylindrical.

The light is also increased by increasing the inten-

sity of the combustion of the hydrogen, as in the Bude light.

The heat of the flame is increased by mixing oxygen with the gas before it burns, so that the carbon and hydrogen may burn together, as in the Bunsen burner and in the blowpipe flame.

The burning candle or oil lamp is a miniature gas-factory.

The candle flame consists of three parts: (1.) an inner zone of unburnt gases, surrounded by (2.) a luminous zone of incomplete combustion, outside of which is (3.) a non-luminous zone of complete combustion.

The blowpipe flame consists of two parts: (1.) the outer, or *oxidizing* flame, and (2.) the inner, or *reducing* flame.

ORGANIC CHEMISTRY.

CLASSIFICATION OF ORGANIC COMPOUNDS.

433. *Organic Compounds.* — As has already been stated, organized bodies are made up chiefly of carbon, hydrogen, oxygen, and nitrogen. All the compounds found in the bodies of animals and plants, and all that can be derived from these by their chemical metamorphosis, are called *organic compounds*, and they are usually arranged together under the head of *organic chemistry*.

Although they contain but few elements, organic compounds are numberless.

Their number, diversity, and complexity are in no way dependent on the so-called *vital force*, but wholly upon the remarkable capacity of the carbon atoms to bind together a great number of atoms and radicals into a complex molecule. This capacity of the carbon atoms makes a great variety of molecular structure possible with even a few elementary atoms.

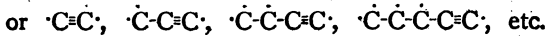
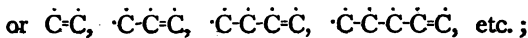
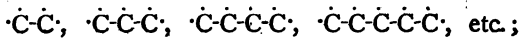
"Organic Chemistry is simply the chemistry of the compounds of carbon, and has no distinctive character except that which the peculiar qualities of this singular element give."

It is important, in this place, to mark the distinction between *organic compounds* and *organized bodies*. Organic compounds, such as marsh gas, ethylene, benzol, alcohol, sugar, morphine, etc., are definite chemical compounds, many of which may be formed by artificial methods ; those

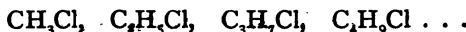
which are solid can, for the most part, be crystallized ; those which are liquid exhibit constant boiling-points. Organized bodies, on the contrary, always consist of mixtures of several definite compounds. They never crystallize, but exhibit a fibrous or cellular structure, and cannot be reduced to the liquid or gaseous state without complete decomposition. Lastly, they are organs, or parts of organs, which are essentially products of vitality, and there is not the slightest prospect of their ever being produced by artificial means.

434. *Hydrocarbons*. — It will be seen that the three hydrocarbons C_2H_6 , C_2H_4 , and C_2H_2 differ from one another by H_2 . There are many series of organic compounds whose terms differ by this amount, and which are called *isologous* series.

If we recall the graphic symbols of these three hydrocarbons, it will be seen that each may give rise to a series by successive addition of CH_2 . Thus we may have



Series of organic compounds whose terms differ from one another by CH_2 are called *homologous* series. There are many such series besides that of the hydrocarbons just mentioned ; thus *methylic chloride*, CH_3Cl , gives by continued addition of CH_2 the series of chlorides,



and from *methylic alcohol*, CH_4O , is derived in like manner the series of homologous alcohols,



If we let n represent the number of carbon atoms in any

term of the above series of hydrocarbons, the number of *hydrogen* atoms in the *first* or *marsh-gas* series will be $2n + 2$; in the *second* or *olefiant-gas* series, $2n$; and in the *third* or *acetylene* series, $2n - 2$. There are two other series of hydrocarbons: the *essential oils*, in which the hydrogen atoms are $2n - 4$; and the *phenyl* series, in which they are $2n - 6$.

A few of the more important hydrocarbons of the first three series are given below:—

Marsh Gas Series.	Olefiant Gas Series.	Acetylene Series.
Methylic hydride, C_1H_4		
Ethylic hydride, C_2H_6	Ethylene, C_2H_4	Acetylene, C_2H_2
Propylic hydride, C_3H_8	Propylene C_3H_6	Allylene, C_3H_4
Butylic hydride, C_4H_{10}	Butylene, C_4H_8	Crotonylene, C_4H_6
Amylic hydride, C_5H_{12}	Amylene, C_5H_{10}	Valerylene, C_5H_8
Hexylic hydride, C_6H_{14}	Hexylene, C_6H_{12}	Allyl(?), C_6H_{10}

Each vertical column of this table forms a homologous series, in which the terms differ by CH_2 , and each horizontal line an *isologous* series, in which the successive terms differ by H_2 . All the hydrocarbons in this table are capable of existing in the separate state. They are all derived from saturated molecules, C_nH_{2n+2} by abstraction of one or more *pairs*, of hydrogen atoms.

Of the *essential-oil* series only one term is known, $C_{10}H_{16}$ (oil of turpentine), all the essential oils being isomeric.

The most important members of the *phenyl* series are:—

Benzol,	C_6H_6
Toluol,	C_7H_8
Xylol,	C_8H_{10}
Cumol,	C_9H_{12}
Cymol,	$C_{10}H_{14}$

The terms of the same homologous series resemble one another in many respects, exhibiting similar transformations.

under the action of given reagents, and a regular gradation of properties from the lowest to the highest ; thus, of the hydrocarbons C_nH_{2n+2} , the lowest terms, CH_4 , C_2H_6 , and C_3H_8 , are gaseous at ordinary temperatures, the highest, containing 20 or more carbon atoms, are solid, while the intermediate compounds are liquids, becoming more and more viscid and less volatile as they contain a greater number of carbon atoms, and exhibiting a constant rise of about 20° in their boiling-points for each addition of CH_2 to the molecule.

435. *Hydrocarbon Radicals*. — By eliminating successive atoms of hydrogen, each of the above hydrocarbons yields a series of compound radicals whose atomicity is in any case equal to the number of hydrogen atoms lost.

Such of these radicals as contain an even number of hydrogen atoms are necessarily artiads and isomeric with either actual or possible hydrocarbons. Those which contain an odd number of hydrogen atoms are necessarily perissads, and cannot without reduplication exist in a free state. Their existence in compounds, however, is undoubted, and hence they have received distinctive names. The names of perissad radicals end in *-yl*.

436. *Oxygenated Radicals*. — The hydrocarbon radicals are usually basic or positive ; but by replacing a portion of the hydrogen by an equivalent of oxygen, each of these radicals may yield an acid or negative radical of the same atomicity. Thus : —

Methyl,	CH_3 ,	yields	Formyl,	CHO
Ethyl,	C_2H_5 ,	"	Acetyl,	C_2H_3O
Propyl,	C_3H_7 ,	"	Propionyl,	C_3H_5O
Butyl,	C_4H_9 ,	"	Butyryl,	C_4H_7O
Amyl,	C_5H_{11} ,	"	Valeryl,	C_5H_9O
Ethylene,	C_2H_4 ,	"	Glycolyl,	C_2H_2O , and Carbonyl, C_2O_2
Propylene,	C_3H_6 ,	"	Lactyl,	C_3H_4O , and Malonyl, $C_3H_2O_2$
Acetylene,	C_2H_2 ,	"	Acetonyl,	C_2H_2O and Succinyl, $C_4H_2O_2$

From the above series of hydrocarbons and radicals, all well-defined organic compounds may be supposed to be formed by combination and substitution.

437. *Alcohols, Fat Acids, Ethers.* — The hydrocarbon radicals above mentioned yield a large number of compounds after the type of water, which are closely allied to the hydrates and oxides, both basic and acid, and to the salts of the metallic and non-metallic elements. "If one of the hydrogen atoms in the molecule of water is replaced by one of the univalent *basic* radicals, methyl, ethyl, propyl, etc., we obtain a class of compounds called *alcohols*, of which our common alcohol is the most important. On the other hand, if the atom of hydrogen is replaced by one of the univalent *acid* radicals, formyl, acetyl, propionyl, etc., we obtain an important class of *acid* compounds, of which acetic acid (vinegar) is the best known, but which also includes a large number of fatty substances closely related to our ordinary fats." Hence these compounds are usually called *fat* (or *fatty*) *acids*.

Basic Hydrates, or Alcohols.

Methylic alcohol (wood-spirit),	$\text{CH}_3 \cdot \text{HO}$
Ethylic alcohol (common alcohol),	$\text{C}_2\text{H}_5 \cdot \text{HO}$
Propylic alcohol,	$\text{C}_3\text{H}_7 \cdot \text{HO}$
Butylic alcohol,	$\text{C}_4\text{H}_9 \cdot \text{HO}$
Amylic alcohol (fusel oil),	$\text{C}_5\text{H}_{11} \cdot \text{HO}$
(with six others already known).	

Acid Hydrates, or Fat Acids.

Formic acid,	$\text{H} \cdot \text{C} \text{HO} \cdot \text{O}$ or $\text{H} \cdot \text{C} \text{HO}_2$
Acetic acid,	$\text{H} \cdot \text{C}_2\text{H}_3\text{O} \cdot \text{O}$ " $\text{H} \cdot \text{C}_2\text{H}_3\text{O}_2$
Propionic acid,	$\text{H} \cdot \text{C}_3\text{H}_5\text{O} \cdot \text{O}$ " $\text{H} \cdot \text{C}_3\text{H}_5\text{O}_2$
Butyric acid,	$\text{H} \cdot \text{C}_4\text{H}_7\text{O} \cdot \text{O}$ " $\text{H} \cdot \text{C}_4\text{H}_7\text{O}_2$
Valerianic acid,	$\text{H} \cdot \text{C}_5\text{H}_9\text{O} \cdot \text{O}$ " $\text{H} \cdot \text{C}_5\text{H}_9\text{O}_2$
(with fifteen others already known).	

When *both* atoms of hydrogen are replaced by *the same basic radical* the compound is called a *simple ether*; when *both* are displaced, but each by a *different basic radical*, the compound is called a *mixed ether*; when *one* is replaced by a *basic* and the *other* by an *acid radical*, so as to form a salt, the compound is called a *compound ether*; and when *both* are replaced by *negative radicals*, an *anhydride*.

1. Simple Ethers.

Methylic ether, $(\text{CH}_3)_2\text{O}$
 Ethylic ether (common ether), $(\text{C}_2\text{H}_5)_2\text{O}$.

2. Mixed Ethers.

Methyl-ethyl ether, $(\text{CH}_3, \text{C}_2\text{H}_5)\text{O}$
 Ethyl-amyl ether, $(\text{C}_2\text{H}_5, \text{C}_5\text{H}_{11})\text{O}$.

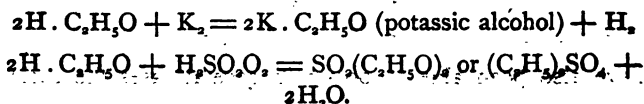
3. Compound Ethers.

Acetic ether (ethylic acetate), $\text{C}_2\text{H}_5 \cdot \text{C}_2\text{H}_3\text{O}_2$
 Butyric-methyl ether (methylic butyrate), $\text{C}_2\text{H}_5 \cdot \text{C}_4\text{H}_7\text{O}_2$
 Nitric ether (ethylic nitrate), $\text{C}_2\text{H}_5 \cdot \text{NO}_3$
 Sulphuric ether (ethylic sulphate), $(\text{C}_2\text{H}_5)_2 \cdot \text{SO}_4$.

4. Anhydrides.

Acetic anhydride, $(\text{C}_2\text{H}_3\text{O})_2\text{O}$
 Valerianic anhydride, $(\text{C}_5\text{H}_9\text{O})_2\text{O}$.

The positive radicals of the alcohols hold an intermediate position between the strong basic radicals on the one hand, and the strong acid radicals on the other; and the same is true of the alcohols themselves, which hold a middle position between the strong bases and the strong acids. The typical hydrogen atom of alcohol may be replaced either by a strong basic metal, like potassium, or by a strong acid radical, like SO_4 . Thus:—



438. *Glycols*. — "If in the double molecule of water we replace one of the pair of hydrogen atoms by any one of the bivalent positive radicals, ethylene, propylene, butylene, etc., we obtain a series of compounds closely related to the alcohols, called *glycols*, and by substituting the related negative radicals we obtain two series of *acids* which stand in the same relation to the glycols that the fat acids do to the alcohols." The first series of acids is usually called the *lactic* series and its acids are *monobasic*. The second series is called the *oxalic* series, and its acids are *dibasic*. The first five members of the glycol series and of each of the related acid series are given below : —

Glycols.

Ethyl glycol, $C_2H_4 \cdot 2HO$
 Propyl glycol, $C_3H_6 \cdot 2HO$
 Butyl glycol, $C_4H_8 \cdot 2HO$
 Amyl glycol, $C_5H_{10} \cdot 2HO$
 Hexyl glycol, $C_6H_{12} \cdot 2HO$.

Lactic Acids.

Glycolic acid, $H_2 \cdot C_2H_2O_2 \cdot O_2$ or $H \cdot C_2H_3O_3$
 Lactic acid, $H_2 \cdot C_3H_4O_2 \cdot O_2$ " $H \cdot C_3H_5O_3$
 Acetonic acid, $H_2 \cdot C_4H_6O_2 \cdot O_2$ " $H \cdot C_4H_7O_3$
 Valerolactic acid, $H_2 \cdot C_5H_8O_2 \cdot O_2$ " $H \cdot C_5H_9O_3$
 Leucic acid, $H_2 \cdot C_6H_{10}O_2 \cdot O_2$ " $H \cdot C_6H_{11}O_3$

Oxalic Acids.

Oxalic acid, $H_2 \cdot C_2O_2 \cdot O_2$ or $H_2 \cdot C_2O_4$
 Malonic acid, $H_2 \cdot C_3H_2O_2 \cdot O_2$ " $H_2 \cdot C_3H_2O_4$
 Succinic acid, $H_2 \cdot C_4H_2O_2 \cdot O_2$ " $H_2 \cdot C_4H_2O_4$
 Lipic acid, $H_2 \cdot C_5H_2O_2 \cdot O_2$ " $H_2 \cdot C_5H_2O_4$
 Adipic acid, $H_2 \cdot C_6H_2O_2 \cdot O_2$ " $H_2 \cdot C_6H_2O_4$

Corresponding to these basic and acid hydrates we have also been able to obtain in several cases the basic

and acid oxides, besides a large number of compound ethers.

439. *Glycerines and Sugars.* — “In the alcohols one hydrogen atom from the original typical molecule (*typical hydrogen*) remains undisturbed. In the glycols there are two such hydrogen atoms, and hence these compounds are frequently called *diatomic alcohols*. Our common glycerine is a *triatomic* alcohol, and may be regarded as formed from water trebly condensed, by replacing one of the group of hydrogen atoms with the trivalent radical glyceryl (C_3H_5). It is probable that a large number of triatomic alcohols or glycerines may hereafter be obtained, but only two are now known.”

Propylic glycerine (common glycerine), $C_3H_5 \cdot 3HO$

Amylic glycerine, $C_5H_7 \cdot 3HO$.

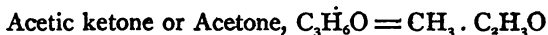
“From the glycerines we may derive acids, anhydrides, and compound ethers, bearing to each other the same relations as those derived from the alcohols of a lower order, but only a few of the possible compounds which our theory would foresee are yet known. Lastly, it appears probable that our common sugars are also constituted after the type of water greatly condensed, and are simply alcohols of a very high order of atomicity.”

440. *Aldehydes.* — These bodies may be regarded as hydrides of the acid radicals. They are named from their corresponding acids. Thus we have:—

Acetic aldehyde,	$H \cdot C_2H_3O$
Propionic aldehyde,	$H \cdot C_3H_5O$
Butyric aldehyde,	$H \cdot C_4H_7O$
Valeric aldehyde,	$H \cdot C_5H_9O$
etc.	etc.

They have a strong affinity for oxygen, and hold an intermediate position between the alcohols and acids.

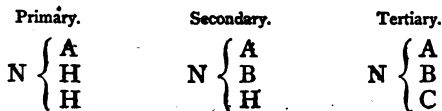
441. *Ketones*. — These are derived from aldehydes by the replacement of one atom of hydrogen by an alcohol radical. Thus,



These compounds outwardly resemble the alcohols, and have a pleasant ethereal odor. Each ketone is isomeric with the next higher aldehyde; but they differ from the aldehydes widely in their chemical relations, for they are comparatively inactive bodies, and show no tendency to unite with oxygen.

442. *Compound Ammonias or Amines*. — These names are given to a class of compounds derived from ammonia, NH_3 , by substitution of alcohol radicals for hydrogen, these radicals being either monatomic or polyatomic. The substitution may take place in one, two, or a greater number of ammonia molecules, thus giving rise to *monamines*, *diamines*, *triamines*, etc. Moreover, the nitrogen in these bases may be replaced by phosphorus, arsenic, or antimony, giving rise to *phosphines*, *arsines*, and *stibines*, bases analogous in composition and properties to the amines.

Ammonia may give up one, two, or all three of its hydrogen atoms in exchange for univalent alcohol radicals (methyl and its homologues, for example), producing *primary*, *secondary*, and *tertiary amines*. If A, B, C, denote three such alcohol radicals, the amines formed by substituting them for hydrogen in ammonia will be represented by the general formulæ:—



In the secondary and tertiary amines the alcohol radicals denoted by A, B, C, may be either the same or different; for example:—

Secondary.		Tertiary.		
$\text{N} \begin{Bmatrix} \text{CH}_3 \\ \text{CH}_3 \\ \text{H} \end{Bmatrix}$	$\text{N} \begin{Bmatrix} \text{CH}_3 \\ \text{C}_2\text{H}_5 \\ \text{H} \end{Bmatrix}$	$\text{N} \begin{Bmatrix} \text{CH}_3 \\ \text{CH}_3 \\ \text{CH}_3 \end{Bmatrix}$	$\text{N} \begin{Bmatrix} \text{CH}_3 \\ \text{CH}_3 \\ \text{C}_2\text{H}_5 \end{Bmatrix}$	$\text{N} \begin{Bmatrix} \text{CH}_3 \\ \text{C}_2\text{H}_5 \\ \text{C}_2\text{H}_5 \end{Bmatrix}$
Dimethyl-amine.	Methyl-ethyl-amine.	Trimethyl-amine.	Dimethyl-ethylamine.	Methyl-ethyl-amine.

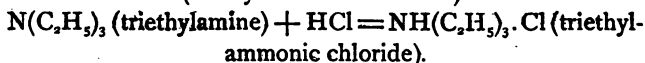
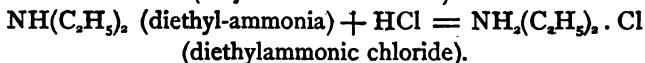
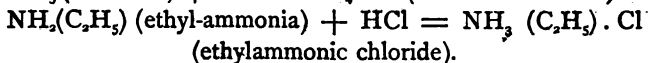
It is clear that amines containing only univalent alcohol radicals must be derived from only one molecule of ammonia; for to bind together two or more such molecules would require the introduction of a polyatomic radical :

thus $\text{N} \begin{Bmatrix} \text{H}_2 \\ (\text{C}_2\text{H}_5)_2 \\ \text{H}_2 \end{Bmatrix}$ is a stable compound, but such a com-

pound as $\text{N} \begin{Bmatrix} \text{H}_2 \\ (\text{C}_2\text{H}_5)_2 \\ \text{H}_2 \end{Bmatrix}$ would split up into two molecules,

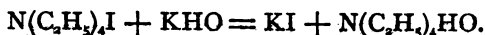
each consisting of $\text{N} \begin{Bmatrix} \text{H}_2 \\ \text{C}_2\text{H}_5 \end{Bmatrix}$. In other words, amines derived from monatomic alcohols must be monamines.

These amines are basic compounds more or less resembling ammonia in odor, having an alkaline reaction on vegetable colors, and uniting with acids to form salts which are analogous in composition to the ammonium salts, and, like the latter, may be regarded either as compounds of ammonium molecules with acids, or of ammonium molecules with elements of the chlorine group and acid radicals analogous thereto. Thus :—



All the salts of these amines, when heated with potash, give off the amine, just as ammonia salts give off ammonia.

The tertiary amines can unite with the chlorides, etc. of alcohol radicals in the same manner as with acids; thus triethylamine, $N(C_2H_5)_3$, unites directly with ethyl-iodide, C_2H_5I , forming a compound which may be regarded either as *triethylamine ethyl-iodide*, $N(C_2H_5)_3 \cdot C_2H_5I$, or as *tetrethylammonic iodide*, $N(C_2H_5)_4 \cdot I$. Now this iodide, when heated with potash, does not give off ammonia or a volatile ammonia base; but it is converted, by exchange of iodine for hydroxyl, into a strongly alkaline base, called *tetrethylammonic hydrate*, which may be obtained in the solid state, and exhibits reactions closely analogous to those of the fixed caustic alkalies. Its formation is represented by the equation:—



Moreover, this base can exchange its hydroxyl for chlorine, bromine, and other acid radicals, just like potash or soda, forming solid crystallizable salts like the iodide above mentioned. These compounds, containing four equivalents of alcohol radical, are, in fact, analogous in every respect to ammonium salts, excepting that the corresponding hydrates are capable of existing in the solid state, whereas ammoniac hydrate, $(NH_4)HO$, splits up, as soon as formed, into ammonia and water. The radicals $N(C_2H_5)_4$, etc., corresponding to ammonium, are not known in the free state.

443. *Amides*.—Compounds exactly analogous to the amines, but with acid radicals instead of alcohol radicals, are called amides; as,—

Acetamide	. . . . .	$NH_2 \cdot C_2HO$
Diacetamide	. . . . .	$NH \cdot (C_2H_3O)_2$
Succinimide	. . . . .	$NH \cdot (C_4H_4O_2)''$
Succinamide	. . . . .	$(NH_2)_2 \cdot (C_4H_4O_2)''$

They are divided (like amines) into *monamides*, *di-amides*, and *triamides*, each of which groups is further subdivided into *primary*, *secondary*, and *tertiary amides*, according as one third, two thirds, or the whole of the hydrogen is replaced by acid radicals.

444. *Compounds of the Alcohol Radicals with the Metals.*

— Several of the alcohol radicals combine with the metals. Thus we have : —

Zn	(C ₂ H ₅) ₂	Zincic ethide,
Zn	(CH ₃) ₂	Zincic methide,
K	(C ₂ H ₅)	Potassic ethide,
Na	(C ₂ H ₅)	Sodic ethide,
Al	(CH ₃) ₃	Aluminic methide,
Pb	(C ₂ H ₅) ₄	Plumbic ethide.
		etc. etc.

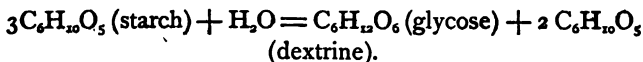
SUGAR, STARCH, AND WOODY FIBRE.

445. Many organic compounds have already been described in the earlier part of the book. Out of the immense number that remain, we shall take up here only a few of the most important.

446. *Grape-Sugar, Glycose, or Dextrose.* — This variety of sugar is very abundantly diffused through the vegetable kingdom. It is found in the juice of grapes (whence its name, *grape-sugar*), plums, cherries, figs, and many other fruits, and may often be seen in a crystalline form on raisins and dried figs. It may be extracted in large quantity from these juices, and also from honey, of which it forms the solid crystalline portion, by washing with cold alcohol, which dissolves the fluid sirup.

It is manufactured on a large scale, in Europe, from starch. A mixture of starch and water, at a temperature of about 55°, is made to flow gradually into a vat, con-

taining boiling water, acidulated with one per cent of sulphuric acid. The starch takes up the elements of water, and is resolved into glucose and dextrine, a compound isomeric with starch itself.



In about half an hour the starch is converted into sugar. The sulphuric acid is neutralized with chalk, forming a deposit of calcic sulphate; and the clear solution of sugar is then boiled down and crystallized. Instead of starch, in this process, paper, flax, cotton, and linen rags, sawdust, or any other form of woody fibre, may be used. The woody fibre is first converted into starch, and then into sugar.

Glucose is much less sweet than cane-sugar, and less soluble in water, requiring 1.5 parts of the cold liquid for solution. It separates from its solutions in water and alcohol in granular, warty masses, which but seldom present crystalline faces. When pure, it is nearly white. In the state of solution it turns the plane of polarization of a ray of light to the right, and hence the name *dextrose*.

Glucose is largely used in Europe for confectionery, for adulterating cane-sugar, and for the manufacture of beer and spirits.

447. *Levulose*. — This sugar, distinguished from dextrose or glucose by being *levorotatory* (that is, turning the plane of polarization to the left), occurs, together with dextrose, in honey, in many fruits, and in other saccharine substances. The mixture of these two sugars in equivalent quantities constitutes *fruit-sugar*, or *inverted sugar*, which is itself levorotatory, because the specific rotatory power of levulose is, at ordinary temperatures, greater than that of dextrose.

Cane-sugar may be *inverted*, that is, transformed into a mixture of equal parts of dextrose and levulose, by warm-

ing with dilute acids : $C_{12}H_{22}O_{11}$ (cane-sugar) $+ H_2O = C_6H_{12}O_6$ (dextrose) $+ C_6H_{12}O_6$ (levulose). The same change is brought about by contact with yeast, or with *pectase*, the peculiar ferment of fruits ; and likewise takes place slowly when a solution of cane-sugar is left to itself.

Levulose is a colorless uncrystallizable sirup, as sweet as cane-sugar, more soluble in alcohol than dextrose. Its rotatory power is much greater than that of dextrose at ordinary temperatures, but diminishes as the temperature rises.

Levulose exhibits, for the most part, the same chemical reactions as dextrose, but is more easily altered by heat or by acids, and, on the contrary, offers greater resistance to the action of alkalies or of ferments.

448. *Cane-Sugar, or Saccharose.* — This most useful substance, $C_{12}H_{22}O_{11}$ ($= 2C_6H_{12}O_6 - H_2O$), is found in the juice of many of the grasses, in the sap of some forest-trees, in the root of the beet and the mallow, and in several other plants. Most sweet fruits contain cane-sugar, together with inverted sugar ; some, as walnuts, hazelnuts, almonds, and coffee-beans, contain only cane-sugar. Honey and the nectars of flowers contain cane-sugar together with inverted sugar ; the sugar in the nectars of cactuses is almost wholly cane-sugar.

Sugar is mostly prepared from the juice of the *sugar-cane* ; but on the continent of Europe, it is largely made from *beet-juice*. In tropical regions it is also manufactured from the juice of the *date-palm* ; and in the Northern United States it is obtained in considerable quantities from the sap of the *rock* or *sugar maple*.

In the manufacture of sugar from sugar-cane the juice is first extracted from the canes by pressure, then mixed with a small quantity of slaked lime, and heated nearly to boiling. The lime serves to neutralize the acid in the

juice, and also to remove the albuminous matter, which, if left in the sugar, would soon cause it to ferment and spoil. The juice is next evaporated in open pans to a thick sirup, which is allowed to cool and crystallize, and is then drained in perforated casks. The liquid drained off is known as *molasses*.

By this process, *raw* or *brown sugar* is obtained. This is *refined* by dissolving it in water, adding albumen (usually from ox-blood), and heating it. The albumen separates most of the impurities from the solution, which is then filtered through bone-black to remove the coloring matter. It is then boiled down in *vacuum pans*, large vessels from which the air is partially exhausted by pumps, in order that the evaporation may be carried on at a lower temperature than in open pans. By this process there is a saving of fuel, while the quantity of sugar obtained is increased. The concentrated sirup is crystallized in conical moulds, with an opening at the bottom for drainage, and thus becomes *loaf-sugar*.

When sugar crystallizes very slowly it forms the large and very hard crystals seen in *rock-candy*. In making loaf-sugar the sirup is frequently stirred, to prevent the formation of these large crystals.

Sugar has a pure, sweet taste, is very soluble in water, — requiring for solution only one third of its weight of cold water, — and is also dissolved by alcohol, but less easily. When moderately heated it melts, and solidifies, on cooling, to a glassy, amorphous mass, familiar as *barley-sugar*.

If cane-sugar be heated to about 210° , it loses two atoms of water, and is converted into *caramel*, a dark-brown substance, much used for coloring brandy and other spirits. At a still higher temperature, an inflammable gaseous mixture is given off, consisting of carbonic oxide, marsh-gas, and carbonic anhydride.

The manufacture of sugar from the sugar-cane, and

other sources, is now one of the largest branches of human industry, but its importance is of comparatively modern date.*

449. *Milk-Sugar, or Lactose.* — This kind of sugar is an important constituent of milk. It is obtained in large quantities by evaporating *whey* to a sirupy state, and purifying the lactose, which slowly crystallizes out, with animal charcoal. It forms white, translucent, four-sided, trimetric prisms, of great hardness. It is slow and difficult of solution in cold water, requiring for that purpose five or six

* Sugar was known to the Greeks and Romans only as a medicine or a curiosity. For several centuries after the Augustan age, we find scarcely any mention of it; and, even so late as the seventh century, Paul of Aegina describes it as "India salt, resembling common salt in color and consistency, but honey in taste and flavor." The sugar-cane appears to have been introduced into Europe by the Saracens, who cultivated it in Rhodes, Cyprus, Crete, and Sicily, in the ninth century. In the fifteenth century, it was transplanted into Madeira and the Canary Isles, whence it was probably brought to America. It became known in England in the fourteenth century; and, in 1329, it was sold in Scotland at one ounce of silver (equal to four dollars of our money) a pound. It did not become an article of ordinary consumption until the beginning of the seventeenth century. Since that time its use has very rapidly increased, and it seems destined to an indefinite extension. "It is so nutritious, wholesome, and agreeable, that there never can be a limit to its use, except in a prohibition or an inability to buy it. Men and nations differ widely in respect to most kinds of food, sauce, and drinks. Neither wheat, rice, flesh, nor potatoes, can command unanimous favor. No article of housekeeping, save sugar, can be named, which is universally acceptable to the infant and the aged, the civilized and the savage."

The annual production of sugar throughout the world is estimated at more than 5,000 millions of pounds, of which nearly 88 per cent is cane-sugar; about 7 per cent, beet-sugar; 4 per cent, palm-sugar; and about 1 per cent, maple-sugar. According to Chambers's *Encyclopædia* (1867), the yearly consumption, *for each inhabitant*, in several great countries, is as follows: Russia, 1½ lbs.; Austria, 1½ lbs.; France, 4 lbs.; Belgium, 6 lbs.; Great Britain, 30 lbs.; United States, 40 lbs.

times its weight; it has a faint, sweet taste, and in the solid state feels gritty between the teeth.

450. *Gum.* — *Gum-arabic*, which is the produce of several species of acacia, may be taken as the most perfect type of this class of bodies. In its purest and finest condition it forms white or slightly yellowish irregular masses, which are destitute of crystalline structure. It is soluble in cold water, forming a viscid, adhesive, tasteless solution, from which the pure soluble gummy principle, or *arabine*, is precipitated by alcohol, and by basic plumbic acetate, but not by the neutral acetate. Arabine is composed of $C_{12}H_{22}O_{11}$, and is consequently isomeric with cane-sugar.

Mucilage, so abundant in linseed, in the roots of the mallow, and in other plants, differs in some respects from gum-arabic, although it agrees in the property of dissolving in cold water. The solution is less transparent than that of gum, and is precipitated by neutral plumbic acetate. *Gum-tragacanth* is chiefly composed of a kind of mucilage to which the name *bassorine* has been given; it refuses to dissolve in water, merely softening and assuming a gelatinous aspect. It is dissolved by caustic alkali. *Cerasine* is the insoluble portion of the gum of the cherry-tree; it resembles bassorine. The composition of these various substances closely agrees with that of starch. Mucilage invariably contains hydrogen and oxygen in the proportion in which they form water, and when treated with acid yields glycose.

Pectine, or the jelly of fruits, is, in its physical properties, closely allied to the foregoing bodies. It may be extracted from various vegetable juices by precipitation with alcohol. It forms, when moist, a transparent jelly, which is soluble in water, tasteless, and dries up to a translucent mass. It is to this substance that the firm consistence of currant and other fruit jellies is ascribed.

451. *Starch, Fecula, or Amidine.* — This is one of the most important and most widely diffused of vegetable principles, being found to a greater or less extent in every plant. Its formula is $C_6H_{10}O_5$, or more probably some multiple thereof, which may be indicated thus: $nC_6H_{10}O_5$. It is most abundant in certain roots and tubers, and in soft stems; seeds often contain it in large quantity. From these sources the starch can be obtained by rasping or grinding the vegetable structure to pulp, and washing the mass upon a sieve. The starch passes through with the liquid, from which it settles as a soft, white, insoluble powder, which may be washed with cold water, and dried at a very gentle heat. Potatoes treated in this manner yield a large proportion of starch. Starch from grain may be prepared in the same manner, by mixing the meal with water to a paste, and washing the mass upon a sieve; a nearly white, insoluble substance called *gluten* is then left, containing a large proportion of nitrogen. The gluten of wheat-flour is extremely tenacious and elastic. The value of meat as an article of food greatly depends upon this substance. Starch from grain is commonly manufactured on the large scale by steeping the material in water for a considerable time. The lactic acid, always developed under such circumstances from the sugar of the seed, disintegrates and partially dissolves the gluten, thereby greatly facilitating the separation of the starch. A still more easy and successful process has lately been introduced, in which a very dilute solution of caustic soda, containing about 200 grains of alkali to a gallon of liquid, is employed with the same view. Excellent starch is thus prepared from rice. Starch is insoluble in cold water, as its mode of preparation sufficiently shows; it is equally insoluble in alcohol, and in other liquids which do not decompose it. To the naked eye it presents the appearance of a soft, white, and often glistening powder; under the microscope it is seen to be alto-

gether destitute of crystalline structure, and to be made up of multitudes of little rounded transparent bodies, or *granules*. The largest are about $\frac{1}{800}$, and the smallest are less than $\frac{1}{3000}$ of an inch in diameter. In the potato (Figure 63) they are considerably larger than in wheat-

Fig. 63.

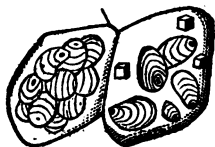
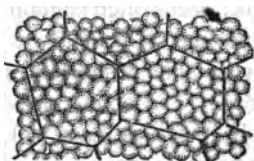


Fig. 64.



flour (Figure 64). These granules consist of concentric layers, formed one after another, about a *nucleus* or centre. Lines indicating these layers can sometimes be seen on the surface of the larger grains, as in those of potato starch in the figure. Since the grains from the same kind of plant are tolerably uniform in size and shape, while they vary much in different species, the microscope will show to what plant starch-grains belong. Adulterations of arrow-root, and of other starchy substances, may thus be detected.

When a mixture of starch and water is heated to near the boiling-point of the latter, the granules burst and disappear, producing, if the proportion of starch be considerable, a thick, gelatinous mass. By the addition of a large quantity of water, this gelatinous starch, or *amidine*, may be so far diluted as to pass in great measure through filter-paper. It is very doubtful, however, how far the substance itself is really soluble in water, at least when cold; it is more likely to be merely suspended in the liquid in the form of a swollen, transparent, and insoluble jelly, of extreme tenuity. Amidine, exposed in a thin layer to a dry atmosphere, becomes converted into a yellowish, horny substance, like gum, which, when put into water, again softens and swells.

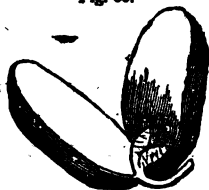
Thin, gelatinous starch is precipitated by many of the metallic oxides, as lime, baryta, and plumbic oxide; also by a large addition of alcohol. By far the most characteristic reaction, however, is that with free *iodine*, which forms with starch a deep indigo-blue compound, which appears to dissolve in pure water, although it is insoluble in solutions containing free acid or saline matter.

Fig. 65.



Starch is the form in which food is stored up in the plant for future use. In the seed, it furnishes the material for the growth of the embryo, before it can draw its nourishment from the earth and the air. It sometimes surrounds the embryo, as in the seed of the onion (Figure 65); and sometimes it is found in the *cotyledons*, or *seed-leaves*, of the embryo itself, as in the seed of the bean (Figure 66). When the seed germinates the starch is dissolved, and converted into dextrine, and this into sugar, which is even more soluble. It is then dissolved in the sap, which conveys it wherever it is needed for the growth of the infant plant.

Fig. 66.



Several forms of starch are extensively used as articles of food. *Arrowroot* is obtained from the roots of a tropical plant, which is cultivated in the West Indies, especially in Bermuda and Jamaica, and to some extent in the East Indies and in Africa. *Tapioca* is also made from the roots of plants which grow in the West Indies, South America, and Africa. *Sago* is extracted from the pith of several species of palm-tree, in India and the islands of the Indian Archipelago. *Corn-starch*, *maizena*, and *farina*, and various other preparations of the kind, are made from the starch of Indian corn, wheat, etc. Potatoes yield from 12 to 27 per cent of

starch; peas and beans from 33 to 36 per cent; wheat-flour, 56 to 72 per cent; rye-meal, 61 per cent; maize, 81 per cent; rice, 83 to 85 per cent.

Starch is also used in large quantities for laundry purposes; in the manufacture of cotton cloth, as a *sizing* for the thread; and in the making of dextrine and grape-sugar.

452. *Dextrine*. — When gelatinous starch is boiled with a small quantity of dilute sulphuric, or almost any acid, it is converted into a soluble gum-like substance, called *dextrine* on account of its dextro-rotatory action on polarized light. The experiment is most conveniently made with sulphuric acid, which may be afterwards withdrawn by saturation with chalk.

When the boiling with the dilute acid is continued for a considerable time, the dextrine first formed undergoes a further change, and becomes converted into glycose. The length of time required for this remarkable change depends upon the quantity of acid present; if the latter be very small, it is necessary to continue the boiling many successive hours, replacing the water which evaporates. With a larger proportion of acid, the conversion is much more speedy.

The change of starch or dextrine into sugar, whether produced by the action of dilute acid or in germinating seeds, takes place quite independently of the oxygen of the air, and is unaccompanied by any secondary product. The acid takes no direct part in the reaction; it may, if not volatile, be all withdrawn without loss after the experiment. The whole reaction lies between the starch and the elements of water, the latter becoming fixed in the new product, as will be seen on comparing the composition of starch and glycose. Dextrine itself has exactly the same composition as the original starch.

Dextrine is sometimes made in the manner above de-

scribed, but more frequently by heating dry potato-starch to 400° , by which it acquires a yellowish tint and becomes soluble in cold water. It is sold in this state under the name of *British gum*. It is often used instead of gum-arabic in calico-printing, and for stiffening certain goods. It is also applied to the back of postage-stamps and other adhesive labels.

When wheaten bread is baked, a small quantity of starch is converted into dextrine on the outside of the crust, forming a brownish glazing.

453. *Starch from Iceland Moss*. — The lichen called *Cetraria Islandica* yields, when boiled in water, a slimy and nearly colorless liquid, which gelatinizes on cooling, and dries up to a yellowish amorphous mass, which does not dissolve in cold water, but merely softens and swells. A solution of this substance in warm water is not affected by iodine, although the jelly is rendered blue. It is precipitated by alcohol, and is converted into glycose by boiling with dilute sulphuric acid. According to Mulder, it contains $C_6H_{10}O_5$. The jelly from certain *algæ* and the so-called *Carrageen moss* closely resembles the above.

454. *Cellulose or Lignine (Woody Fibre)*. — This substance, $nC_6H_{10}O_5$, is the fundamental material of the structure of plants, and forms a large proportion of the solid parts of every vegetable. *Woody fibre* or *tissue* is strictly cellulose with other substances superadded, incrusting the walls of the original cells, and giving them stiffness. Thus woody tissue, even when freed as much as possible from coloring matter and resin by repeated boiling with water and alcohol, yields, on analysis, a result indicating an excess of hydrogen above that required to form water with the oxygen, besides traces of nitrogen. Pure cellulose, on the other hand, has the same chemical composition as starch.

The properties of cellulose may be conveniently studied in fine linen and cotton, which are almost entirely com-

posed of it, the associated vegetable principles having been removed or destroyed by the treatment to which the fibre has been subjected. Pure cellulose is tasteless, insoluble in water and alcohol, and absolutely innutritious ; it is not sensibly affected by boiling water, unless it happens to have been derived from a soft or imperfectly developed portion of the plant, in which case it is rendered pulpy. Dilute acids and alkalis exert but little action on it, even at a boiling temperature ; strong oil of vitriol converts it, in the cold, into a nearly colorless, adhesive substance, which dissolves in water, and has the properties of dextrine. This curious and interesting experiment may be conveniently made by very slowly adding concentrated sulphuric acid to half its weight of lint, or linen cut into small shreds, taking care to avoid any rise of temperature, which would be attended with charring or blackening. The mixing is completed by trituration in a mortar, and the whole left to stand a few hours ; after which it is rubbed up with water, warmed, and filtered from a little insoluble matter. The solution may then be neutralized with chalk, and again filtered. The gummy liquid retains lime, partly in the state of sulphate, and partly in combination with sulpholignic acid, — an acid composed of the elements of sulphuric acid in union with those of cellulose. If the liquid, previous to neutralization, be boiled during three or four hours, and the water replaced as it evaporates, the dextrine becomes entirely changed to glucose. Linen rags may, by these means, be made to furnish more than their own weight of sugar.

455. *Vegetable Parchment.* — When paper is immersed for a short time in a mixture of two volumes of oil of vitriol and one of water, and thoroughly cleansed by repeated washings with water, and finally with ammonia, it is changed into a substance resembling parchment, and often called *vegetable parchment*, or *parchment paper*.

"The alteration which takes place in the paper is of a very remarkable kind. No chemical change is effected, nor is the weight increased; but it appears that a molecular change takes place, and the material is placed in a transition state between the cellulose of woody fibre and dextrine."

Vegetable parchment is now extensively used instead of parchment for legal and other documents. In some respects it is preferable to the old kind, for insects attack it less.

456. *Xyloidine and Pyroxyline*.—If starch be mixed with nitric acid of specific gravity 1.5, it is converted into a transparent, colorless jelly, which, when put into water, yields a curdy, insoluble substance called *xyloidine*. When dry it is white and tasteless, insoluble even in boiling water, but freely dissolved by dilute nitric acid, and the solution yields oxalic acid when boiled. Other substances belonging to the same class also yield xyloidine. Paper dipped into the strongest nitric acid, quickly plunged into water, and afterwards dried, becomes in great part so changed; it assumes the appearance of parchment, and becomes remarkably combustible.

If pure, finely divided woody matter, as cotton-wool, be steeped for a few minutes in a mixture of nitric acid of sp. gr. 1.5 and concentrated sulphuric acid, then squeezed, thoroughly washed, and dried by very gentle heat, it will be found to have increased in weight about 70 per cent, and to have become highly explosive, taking fire at a temperature not much above 149° C. (300° F.), and burning without smoke or residue. This is *pyroxyline*, the *gun-cotton* of Professor Schönbein.

Xyloidine and pyroxyline are substitution-products consisting of starch and cellulose, in which the hydrogen is more or less replaced by *nitryl*, NO_2 . Xyloidine consists of $n\text{C}_6\text{H}_5(\text{NO}_2)\text{O}_5$. Of pyroxyline several varieties are

known, distinguished by their different degrees of stability and solubility in alcohol, ether, and other liquids. One of the less highly nitrated kinds dissolves readily in a mixture of ether and alcohol, and yields a solution termed *colloidion*. This is largely used for the purpose of forming a thin coating on glass for photographic purposes. It is also used in surgery to form an air-tight covering for wounds and burns.

VEGETABLE ACIDS.

457. *Oxalic Acid*. — Oxalic anhydride, C_2O_3 , is not known in a free state. It is found in the juice of wood-sorrel (*oxalis acetosella*, from which it takes its name), and of many other plants, in combination with potash or lime. With water it forms *oxalic acid*. This is a crystalline substance, and is very poisonous. It separates from a hot solution in colorless, transparent crystals consisting of $H_2C_2O_4 \cdot 2H_2O$. The two molecules of crystallization water may be expelled by a very gentle heat, the crystals crumbling down to a soft white powder, consisting of anhydrous oxalic acid, $C_2H_2O_4$, which may be sublimed in great measure without decomposition. The crystallized acid, on the contrary, is decomposed by a high temperature. The crystals of oxalic acid dissolve in 8 parts of water at 15.5° , and in their own weight, or less, of hot water; they are also soluble in spirit. The aqueous solution has an intensely sour taste and most powerful acid reaction, and is highly poisonous. The proper antidote is chalk or magnesia.

Oxalic acid is much used in cotton-printing and straw-bleaching, and is prepared in very large quantities by the action of caustic potash on sawdust. Crude potassic oxalate is thus formed, which, by means of lime, is converted

into the insoluble calcic oxalate, and this is decomposed by sulphuric acid.

458. *Malic Acid*. — This compound, $H_2.C_4H_4O_5$, or $C_4H_6O_5$, is one of the most abundant of the vegetable acids. It is found in pears and apples, from which (Latin, *malum*) it takes its name; in currants, barberries, and many other fruits. It is often associated with citric acid.

Malic acid is colorless, slightly deliquescent, and very soluble in water; alcohol also dissolves it. The aqueous solution has an agreeable acid taste; it becomes mouldy and spoils by keeping.

459. *Gallic Acid*. — This acid, $H.C_7H_5O_5$, or $C_7H_6O_5$, exists in certain plants, as sumach, hellebore root, the acorns of *Quercus agrifolia*, green and black tea, etc. The simplest method of preparing the acid in quantity is to mix powdered nut-galls* with water to a thin paste, and expose the mixture to the air in a warm situation for two or three months, adding water from time to time, to replace that lost by drying up. The mouldy, dark-colored mass thus produced may then be strongly pressed in a cloth, and the solid portion boiled in a considerable quantity of water. The filtered solution deposits, on cooling, abundance of gallic acid, which may be drained and pressed, and finally purified by recrystallization.

Gallic acid forms small, feathery, and nearly colorless crystals, which have a beautiful silky lustre; they contain $C_7H_6O_5$, with some water of crystallization. It requires for solution 100 parts of cold and only 3 parts of boiling water; the solution has an acid and astringent taste, and is gradually decomposed by keeping. Gallic acid does not precipitate gelatine; with ferrous salts it produces no change; but with ferric salts it forms a deep bluish-black precipitate, which disappears when the liquid

* Nut-galls are excrescences produced on the leaves of a species of oak — the *Quercus infectoria* — by the puncture of an insect.

is heated, from the reduction of the ferric to ferrous salt at the expense of the gallic acid.

Gallic acid, heated to about 215° , is resolved into carbonic anhydride, and *pyrogalllic acid*, $C_6H_4O_3$, which sublimes in crystalline plates.

Gallic acid and pyrogalllic acid reduce salts of gold and silver to the metallic state. It is on this property that their application in photography depends.

460. *Tannic Acids, or Tannins*. — These substances constitute the astringent principles of plants, and are widely diffused, in one form or other, through the vegetable kingdom. It is possible that there may be several distinct modifications of tannic acid, which differ among themselves in some particulars. The astringent principle of oak-bark and nut-galls, for example, is found to precipitate ferric salts bluish-black, while that from the leaves of the sumach and tea-plant is remarkable for giving, under similar circumstances, precipitates which have a tint of green. The color of a precipitate is, however, too much influenced by external causes to be relied upon as a proof of essential difference.

After the reaction with ferric salts, the most characteristic feature of tannic acid is that of forming insoluble compounds with a great variety of organic, and especially animal substances, — as solutions of starch and gelatine, solid muscular fibre, skin, etc., — which then acquire the property of resisting putrefaction; it is on this principle that *leather* is manufactured. Gallic acid, on the contrary, is useless in the operation of tanning.

Gallotannic acid, or *tannin*, $C_{27}H_{22}O_{17}$, may be prepared from nut-galls. It forms a slightly yellowish, friable, porous mass, without the least tendency to crystallization. It is very soluble in water, less so in alcohol, and very slightly soluble in ether. It reddens litmus, and has a pure astringent taste without bitterness.

Ferrous salts are unchanged by solution of gallotannic acid; *ferric salts*, on the contrary, give with it a deep bluish-black precipitate, which is the basis of *writing-ink*. Hence the value of an infusion or tincture of nut-galls as a test for the presence of iron.

461. *Tartaric Acid*. — This compound, $H_2.C_4H_4O_6$ or $C_4H_6O_6$, is the acid of grapes, tamarinds, pineapples, and of several other fruits, in which it occurs in the state of an acid potassium salt; calcic tartrate is also occasionally met with. The tartaric acid of commerce is wholly prepared from *tartar*, or *argol*, an impure acid potassic tartrate deposited from wine, or rather from grape-juice in the act of fermentation. This substance is purified by solution in hot water, with the aid of a little pipe-clay and animal charcoal to remove the coloring matter of the wine, and subsequent crystallization; it then constitutes *cream of tartar*, and serves for the preparation of the acid. Liebig has lately found that tartaric acid is artificially produced by the action of nitric acid upon milk-sugar.

Tartaric acid forms colorless, transparent crystals, often of large size, which are permanent in the air, and inodorous; they dissolve with great facility in water, both hot and cold, and are soluble also in alcohol. The solution reddens litmus strongly, and has a pure acid taste. The aqueous solution is dextro-rotatory. This solution is gradually spoiled by keeping. Tartaric acid is consumed in large quantities by the calico-printer, being employed to evolve chlorine from solution of bleaching-powder in the production of white or *discharged* patterns upon a colored ground.

462. *Tartrates*. — *Cream of tartar*, or *acid potassic tartrate*, $KC_4H_5O_6$, the origin and preparation of which have been already described, forms irregular groups of small transparent or translucent prismatic crystals. It dissolves pretty freely in boiling water, but the greater part separates as the solution cools, leaving about $\frac{1}{10}$ or less dissolved in

the cold liquid. The salt has an acid reaction and a sour taste.

Potassio-sodic tartrate (Rochelle salt), $\text{KNaC}_4\text{H}_4\text{O}_6 \cdot 4\text{H}_2\text{O}$, is made by neutralizing with sodic carbonate a hot solution of cream of tartar, and evaporating to the consistence of thin sirup. It separates in large, transparent, prismatic crystals, the faces of which are unequally developed; these effloresce slightly in the air, and dissolve in 1.5 parts of cold water. Acids precipitate cream of tartar from the solution. Rochelle salt has a mild saline taste, and is used in medicine.

Potassio-antimonious tartrate, or tartar emetic, is easily made by boiling antimonious trioxide in solution of cream of tartar. It forms crystals which dissolve without decomposition in 15 parts of cold and 3 of boiling water, and have an acrid and extremely disagreeable metallic taste. The dry salt, heated on charcoal before the blowpipe, yields a globule of metallic antimony. The crystals contain $\text{K}(\text{SbO}) \cdot \text{C}_4\text{H}_4\text{O}_6$, with some water of crystallization; the group SbO acting as a univalent radical, and replacing one atom of hydrogen.

463. *Citric Acid*. — This acid, $\text{H}_3 \cdot \text{C}_6\text{H}_5\text{O}_7$, or $\text{C}_6\text{H}_8\text{O}_7$, is obtained in large quantities from the juice of lemons; it is found in many other fruits, as gooseberries, currants, etc., in conjunction with malic acid. In the preparation of this acid the juice is allowed to ferment a short time, in order that mucilage and other impurities may separate and subside; the clear liquor is then carefully saturated with chalk, whereby insoluble calcic citrate is produced. This is thoroughly washed, decomposed by the proper quantity of sulphuric acid, diluted with water, and the filtered solution is evaporated to a small bulk, and left to crystallize. The product is drained from the mother-liquor, redissolved, digested with animal charcoal, and again concentrated to the crystallizing point.

Citric acid crystallizes in two different forms. The crystals which separate by spontaneous evaporation from a cold saturated solution contain $C_6H_8O_7 \cdot H_2O$, whereas those which are deposited from a hot solution have a different form and contain $2C_6H_8O_7 \cdot H_2O$. Citric acid has a pure and agreeable acid taste, and dissolves, with great ease, in both hot and cold water; the solution strongly reddens litmus, and, when long kept, is subject to spontaneous change.

This acid is used in silk-dyeing, in calico-printing, and in medicine.

Citric acid is sometimes adulterated with tartaric acid; the fraud is easily detected by dissolving the acid in a little cold water, and adding to the solution a small quantity of potassic acetate. If tartaric acid be present, a white crystalline precipitate of cream of tartar will be produced on agitation.

FATS, OILS, AND RESINS.

464. *Fats and Oils.*—The fats and fixed oils (fats being merely solid or semi-fluid oils) form an important and well-defined group of organic compounds, which are obtained abundantly from both the animal and the vegetable kingdom. They are lighter than water, having a specific gravity ranging from about .91 to .94. They have different degrees of solidity, and do not consist of any single substance in a state of purity, but are for the most part mixtures, in varying proportions, of four different but closely allied bodies: *stearine* (from *στέαρ*, suet); *palmitine*, so called from palm-oil, in which it is abundant; *margarine* (from *μάργαρον*, a pearl, owing to its pearly lustre); and *oleine*. The first three are solid at ordinary temperatures, while the fourth is liquid. The larger the proportion of

oleine it contains, the softer is the fat, and the lower its melting-point.

All fats are soluble in ether, and somewhat so in alcohol. Oil of turpentine and benzol dissolve them readily, and the different fats and oils may be mixed with each other in all proportions.

The fats and oils cannot be distilled without decomposition. Hence the term *fixed oils* is applied to them to distinguish them from the *volatile oils*, which bear distillation without change. At about 260° (500° F.) the fats and oils begin to give off acrid vapors, and at a little above 316° (600° F.) they are rapidly decomposed, giving a mixture of solid and liquid hydrocarbons, water, fatty acids, and a peculiarly irritating substance called *acroleine*.

465. *Saponification*. — When the oils or fats are boiled with an alkali they undergo the remarkable change called *saponification*. The fat is decomposed into a *fatty acid* and *glycerine*. The acid combines with the alkali to form *soap*, and the glycerine passes into solution. The reaction, when potash is used, is as follows: $(C_3H_5)'''(C_{18}H_{35}O_2)_3$ (stearine) $+ 3KHO = 3KC_{18}H_{35}O_2$ (potassic stearate) $+ (C_3H_5)'''(HO)_3$ (glycerine). Both the soaps and the fats, then, are *salts*; the fats being organic salts of the trivalent radical *glyceryl*, C_3H_5 .

The fats may also be decomposed by distillation with steam at a temperature between 260° and 316° . The products of the decomposition pass over together, but the fat acids, on account of their insolubility and lower specific gravity, separate from the glycerine in the condenser.

The reaction in this process is exactly similar to the other. $(C_3H_5)(C_{18}H_{35}O_2)_3$ (stearine) $+ 3H_2O = 3(H.C_{18}H_{35}O_2)$ (stearic acid) $+ (C_3H_5)(HO)_3$ (glycerine).

466. *Glycerine*. — Glycerine, the *hydrate* of the radical *glyceryl*, is a colorless viscid liquid, of an intensely sweet taste (whence its name, which is from γλυκύς, sweet),

soluble in water and alcohol, but nearly insoluble in ether. Its specific gravity is 1.27. It is used in medicine, in making copying-ink, and as a lubricating agent.

467. *The Fat Acids*.—Among the most important of these acids (of which some twenty are known) are *palmitic*, *oleic*, *stearic*, and *margaric* acids.

Palmitic acid, $C_{16}H_{32}O_2$, or $H.C_{16}H_{31}O_2$, is a colorless, solid body without taste or smell, lighter than water. It is insoluble in water, but dissolves abundantly in boiling alcohol or ether. The solutions are acid, and, when concentrated, solidify in a mass on cooling. When dilute, they yield the acid in tufts of slender needles. When heated in a dish, it boils and evaporates without residue, and may be distilled almost without change. When gently heated in the air, it is but slightly altered; but at higher temperatures it takes fire, and burns with a bright smoky flame, like other fats.

Oleic acid, $C_{18}H_{34}O_2$, or $H.C_{18}H_{33}O_2$, crystallizes from alcoholic solution in dazzling white needles, melting at 14° to a colorless oil, which solidifies at 4° to a hard, white, crystalline mass, expanding considerably at the same time. The acid volatilizes in a vacuum without decomposition. It is tasteless and inodorous, insoluble in water, very soluble in alcohol, and dissolves in all proportions in ether. In the solid state it oxidizes but slowly in the air; but when melted it rapidly absorbs oxygen, acquiring a rancid taste and smell and a decided acid reaction.

Large quantities of crude oleic acid are now obtained in the manufacture of stearine candles, by treating with dilute sulphuric acid the lime-soap resulting from the action of lime upon tallow. The fatty acids resulting from the decomposition are washed with hot water, and solidify in a mass on cooling; and this mass, when subjected to pressure, yields a liquid rich in oleic acid, but still retaining a considerable quantity of stearic acid. After remaining for

some time in a cold place, it deposits a quantity of solid matter, and the liquid decanted from this is sent into the market as *oleic acid* or *red oil*. It may be purified by the process just described.

Stearic acid, $C_{18}H_{36}O_2$, or $H.C_{18}H_{35}O_2$, is most abundant in the more solid fats of the animal kingdom, especially in beef and mutton suet, but exists also in the softer fats, such as the butter of cows' milk, human fat, and in spermaceti. It occurs also in vegetable fats, especially those of cacao-beans, of the berries of *Cocculus indicus*, etc.

Pure stearic acid is tasteless and inodorous, and has a distinct acid reaction. At low temperatures it is heavier than water, having a specific gravity of 1.01 at 0° ; but between 9° and 10° its specific gravity is the same as that of water. It melts at $69^\circ - 69.2^\circ$ to a colorless oil, which, on cooling, solidifies to a white, fine, scaly, crystalline mass. When heated it distils, for the most part, without alteration.

Margaric acid, according to Chevreul and many other chemists, has the formula $C_{17}H_{34}O_2$, or $H.C_{17}H_{33}O_2$; but Heintz and others consider it to be a mixture of stearic acid with other fat acids of lower melting-points.

Palmitine, oleine, stearine, and *margarine*, as already intimated, are salts formed by these acids with *glyceryl*.

468. *Soaps*. — Soaps consist of mixtures of the sodic or potassic salts of stearic, palmitic, oleic, and other fatty or oily acids, and are produced by saponifying tallow, olive-oil, and other fats, with caustic alkalies. The soda-soaps are called *hard soaps*; they separate from the alkaline liquor, on addition of common salt, in hard, unctuous masses, which are the soaps in common use: this mode of separation is called *salting out*. The potash-soaps, on the other hand, cannot be thus separated; for, on adding salt to their solution, they are decomposed, and converted into soda-soaps; but they are obtained in a semi-

solid state by evaporating the solution. The products, called *soft soaps*, always contain a considerable excess of alkali, and are used for cleansing and scouring when a powerful detergent is required.

469. *Drying and Non-Drying Oils*. — The *fixed* oils are divided into *drying* and *non-drying oils*. The former become dry and solid from oxidation, when spread out thin and exposed to the air ; while the latter remain unaltered. The chief drying oils are those of linseed, hemp, poppy, and walnut, all much used in paints and varnishes ; and the most important non-drying oils are olive-oil, almond-oil, and colza-oil, which are extensively used in making soap, candles, and illuminating-oils, in wool-dressing, and for many other purposes. Castor-oil seems to form a connecting link between these two classes of oils, as it gradually becomes hard by long exposure to the air.

The drying property of oils may be much increased by heating them with about .05 of their weight of *litharge*, which becomes completely dissolved by the oil. Manganic dioxide may be used for the same purpose. Linseed-oil which has been thus treated is known as *boiled oil*.

470. *Wax*. — *Beeswax* is to be regarded as an animal secretion, since bees, even if fed upon pure sugar only, have the power of converting it into wax. At ordinary temperatures it is tough and solid ; it has a yellow color and a peculiar smell. Exposed to the air in thin slices it becomes bleached, and is then somewhat less fusible. It may also be bleached with nitric acid and with chlorine ; but the latter is objectionable, as a substitution of chlorine for a part of the hydrogen of the wax occurs, and when candles made from the wax are burned, irritating vapors of muriatic acid gas are evolved.

Beeswax appears to be a mixture of fatty acids, salts of fatty acids, and other substances which have been but imperfectly examined.

The various forms of *vegetable wax* resemble in many respects the fixed oils, but their chemical composition has not been thoroughly investigated. They are solid or semi-solid substances ; easily broken when cold, but soft and pliable when moderately warm, and melting below 100° . They are insoluble in water and cold alcohol, but dissolve readily in ether ; they burn with a bright flame, and are not volatile. They are found as exudations on leaves and fruits, where they form the *glaucous* surface which repels water. Some fruits, as the bayberry, are thickly coated with wax.

471. *The Volatile or Essential Oils.* — The odorous principles of most plants are certain compounds consisting chiefly of carbon and hydrogen. Their boiling-point is considerably above 100° (212° F.), yet they emit at ordinary temperatures minute quantities of intensely odorous vapor. They have a certain resemblance to the fixed oils in being inflammable, sparingly soluble in water, and freely soluble in alcohol and in ether ; but they feel harsh, instead of unctuous, when rubbed upon the skin.

As a general thing, they exist ready formed in the plant, being enclosed in little sacs or cells, which are often visible to the naked eye, as in orange-peel. They vary in specific gravity, but are generally lighter than water. Most of them have a yellowish color, deepening by exposure to the air, from which they absorb oxygen, and are thus gradually converted into solids or *resins*. The oils which absorb oxygen most rapidly have in general the strongest odor. Nitric acid oxidizes most of them with great violence.

Miller arranges these oils in three classes : (1) *pure hydrocarbons* ; (2) *oxidized essences* ; and (3) *sulphuretted essences*.

(1.) Of the first group, *oil of turpentine*, $C_{10}H_{16}$, may be taken as the type. The other oils of the group (oils of lemon, bergamot, black pepper, etc.) have the same com-

position. Many of them cannot be distinguished from each other except by their action on polarized light. They rapidly absorb muriatic acid gas, and yield compounds called *artificial camphors*, some of which crystallize like common camphor, while others remain liquid. They also combine with water to form solid volatile crystalline substances which resemble camphor even more closely, both in composition and properties. When exposed to the air, they oxidize into resins.

Oil of turpentine is obtained from various species of pine. It is largely used in making varnish, since it readily dissolves the resins, and, on volatilizing, leaves them behind as a transparent coating. It dissolves sulphur and phosphorus, and is one of the best solvents for india-rubber.

(2.) The *oxidized essences* may be subdivided into several classes, of which the *camphors* are the most important.

Common or *laurel camphor*, $C_{10}H_{16}O$, is obtained mainly from the *Laurus camphora*, but is also produced in small quantity by many other plants, which appear to produce it by the oxidation of their essential oils. This is easily understood, as the formula of camphor is the same as that of oil of turpentine, etc., with one atom of oxygen added. The oils of lavender, rosemary, pennyroyal, spearmint, etc., contain camphor in solution.

Camphor has a peculiar odor, and an aromatic taste, at first hot and afterwards cooling. It floats in water, in which it is sparingly soluble; but is dissolved freely by alcohol, ether, acetic acid, and the essential oils. It is very inflammable, and burns with a white smoky flame. It volatilizes slowly at ordinary temperatures; if kept in glass bottles, its vapor condenses in octohedral crystals on the cooler parts of the glass. If a coil of red-hot platinum wire be suspended just over a lump of camphor, the metal continues to glow and the camphor burns slowly until it is all consumed.

(3.) The basis of the *sulphuretted essences* is a hydrocarbon termed *allyl*, C_3H_5 . Common *garlic* yields a volatile oil which is a mixture of allylic oxide and allylic sulphide; and the essences of *onions*, *assafœtida*, and many other plants, are similar oils. The oils of *mustard* and *horseradish* consist chiefly of *allylic sulphocyanide*.

472. *The Resins*. — These substances are produced abundantly by certain plants, and are of considerable commercial importance, being extensively used in making the different kinds of varnish. In general they are formed by the oxidation of the essential oils of the plants. Hence they often have the composition of oxides of the hydrocarbon $C_{10}H_{16}$, or of a hydrocarbon derived from this, having lost a certain number of atoms of H in exchange for half as many atoms of O.

As a class, the resins are insoluble in water, but soluble in alcohol, especially when heated with it. They are transparent or translucent brittle solids; are insulators of electricity, and become negatively electric by friction; fuse at a moderate temperature, are very inflammable, and burn with a white smoky flame. Heated in close vessels, they are decomposed and yield various hydrocarbons.

Common resin, *rosin*, or *colophony*, furnishes, perhaps, the best example of the class. It is the resinous substance which remains when turpentine or pine resin is heated till the water and volatile oil are expelled, and is a mixture of two distinct resinous acids, *abietic acid* and *pinic acid*. An alcoholic solution of abietic acid, precipitated by sulphuric acid, yields another acid called *sylvic acid*, isomeric with pinic acid.

Lac is a very valuable resin, much harder than colophony, and easily soluble in alcohol; three varieties are known in commerce: *stick-lac*, *seed-lac*, and *shellac*. It is used in varnishes, and in stiffening hats, and very largely in the preparation of sealing-wax, of which it forms the chief in-

redient. Crude lac contains a red dye called *lac-dye*, which is partly soluble in water. Lac dissolves in considerable quantity in a hot solution of borax. India ink, rubbed up with this liquid, forms a most excellent *label-ink* for the laboratory, as it is unaffected by acid vapors, and, when once dry, becomes nearly insoluble in water.

Mastic, *dammar-resin*, and *sandarac* are resins largely used by the varnish-maker. *Dragon's-blood* is a resin of a deep-red color. *Copal* is also a very valuable substance; it differs from the other resins in being but slowly dissolved by alcohol and essential oils. It may be mixed, however, in the melted state, with oils, and is thus made into varnish. *Amber* appears to be a fossil resin; it is found accompanying brown-coal or lignite.

Most of the resins, when exposed to destructive distillation, yield oily products, usually hydrocarbons, which have been studied with partial success. Great difficulties occur in these investigations; the task of separating and isolating bodies which scarcely differ except in their boiling-points is exceedingly troublesome.

473. *Balsams*. — These are natural mixtures of resins with volatile oils. They differ very greatly in consistence, some being quite fluid, others solid and brittle. By keeping, the softer kinds often become hard. Balsams may be conveniently divided into two classes: those which, like *common* and *Venice turpentine*, *Canada balsam*, *Copaiba balsam*, etc., are natural varnishes, or solutions of resins in volatile oils, and those which contain benzoic or cinnamic acid in addition, as *Peru* and *Tolu balsams*, and the solid resinous *benzoin*, commonly called *gum-benzoin*.

474. *Gum Resins*. — These substances are the milky juices of many plants solidified by exposure to the air. They consist chiefly of the resins and essential oils of the plants, mixed with a large proportion of gum; consequently they form an *emulsion* when rubbed up with water,

the gum becoming dissolved and retaining the resin and oil in suspension. Many of them are used in medicine ; as *assafœtida*, *aloes*, *galbanum*, *gamboge*, *myrrh*, *scammony*, etc.

Caoutchouc, or *india-rubber*, the thickened milky juice of several species of *Ficus*, *Euphorbia*, and other trees growing in tropical countries, is essentially a mixture of several hydrocarbons isomeric with turpentine oil. When pure, it is nearly white, the dark color of commercial caoutchouc being due to the effects of smoke and other impurities. It is softened, but not dissolved, by boiling water ; it is also insoluble in alcohol. In pure ether, chloroform, carbonic disulphide, rectified oil of turpentine, and coal naphtha it dissolves, and is left unchanged on the evaporation of the solvent. At a temperature a little above the boiling-point of water, caoutchouc melts, but never afterwards returns to its former elastic state. Few chemical agents affect this substance ; hence its great use in chemical apparatus.

Caoutchouc combines with variable proportions of sulphur. The mixtures thus obtained are called *vulcanized india-rubber* ; they are more permanently elastic than pure caoutchouc.

Vulcanite, or *ebonite*, is caoutchouc mixed with half its weight of sulphur, and hardened by pressure and heating. It is very hard, takes a high polish, and is used for making combs, knife-handles, buttons, etc. It is also especially distinguished by the large quantity of negative electricity which it evolves when rubbed.

Gutta-percha, the hardened milky juice of *Isonandra percha*, a large tree growing in Malacca and many of the islands of the Eastern Archipelago, is similar in composition to caoutchouc, and resembles it in many of its properties, but is harder and less elastic. At ordinary temperatures it retains any shape which may have been impressed upon it ; but below 100° (212° F.) it becomes so soft that it may be moulded like wax, and can be used for taking casts

and impressions, since it copies the finest lines with fidelity. It can also be welded while in this softened state. Below 43° (110° F.) it again becomes hard and extremely tenacious. It is quite insoluble in and impervious to water, and being also an excellent electric insulator, is extensively used as a casing for submarine telegraph wires.

The applications of these two gum-resins in the arts are almost innumerable, and are continually increasing.

NATURAL ORGANIC BASES, OR ALKALOIDS.

475. *Their Nature, etc.* — The organic alkaloids constitute a remarkable and most interesting group of bodies; they are met with in various plants, some of them also in animals. They are, for the most part, sparingly soluble in water, but dissolve in hot alcohol, from which they often crystallize in a very beautiful manner on cooling. Several of them, however, are oily, volatile liquids. The taste of the vegetable alkaloids, when in solution, is usually intensely bitter, and their action upon the animal system exceedingly energetic. They all contain a considerable quantity of nitrogen, and are very complicated in constitution. They are also very numerous; but in this elementary work we can take up only a few of the leading ones.

None of the vegetable organic bases have yet been formed by artificial means; and their constitution is far from being completely understood. There can be no doubt, however, that, like the artificial bases, they are substitution products of ammonia.

All natural alkaloids which have been examined (with the exception of *conine*) are tertiary bases, that is, ammonia with all three of its hydrogen atoms replaced.

476. *Morphine, or Morphia.* — This alkaloid, $C_{17}H_{19}NO_3$, is the chief active principle of opium; it is the most

characteristic body of the group, and the earliest known; dating back to the year 1804, when it was discovered by Sertürner.

Opium, the solidified juice of the poppy-capsule, is a very complicated substance, containing, besides morphine, many other alkaloids in very variable quantities, combined with sulphuric acid and meconic acid. In addition to these, there are gummy, resinous, and coloring matters, caoutchouc, etc., besides mechanical impurities, as chopped leaves. The opium of Turkey is the most valuable, and contains the largest quantity of morphine; the opiums of Egypt and of India are considerably inferior. Opium has been produced in England of the finest quality, but at great cost.

Morphine, when crystallized from alcohol, forms small but very brilliant prismatic crystals, which are transparent and colorless. It requires at least 1,000 parts of water for solution, tastes slightly bitter, and has an alkaline reaction. These effects are much more evident in the alcoholic solution. It dissolves in about 30 parts of boiling alcohol, and with great facility in dilute acids; it is also dissolved by excess of caustic potash or soda, but scarcely by excess of ammonia. When heated in the air, morphine melts, inflames like a resin, and leaves a small quantity of charcoal, which easily burns away. It is a powerful narcotic.

The most characteristic and best-defined salt of this base is the *hydrochloride*. It crystallizes in slender, colorless needles, arranged in tufts or stellated groups, soluble in about 20 parts of cold water, and in its own weight at the boiling heat. The crystals contain 3 molecules of water. The *sulphate*, *nitrate*, and *phosphate* are crystallizable salts; the *acetate* crystallizes with great difficulty, and is usually sold in the state of a dry powder. The artificial *meconate* is sometimes prepared for medicinal use.

477. *Cinchonine and Quinine*. — It is to these alkaloids

that the valuable medicinal properties of the *Peruvian barks* are due. They are associated in the barks with sulphuric acid, and with a special acid, called the *quinic* or *kinic*. Cinchonine is contained in largest quantity in the pale bark, or *Cinchona condaminea*; quinine in the yellow bark, or *Cinchona cordifolia*; the *Cinchona oblongifolia* contains both.

Pure *cinchonine* or *cinchonia*, $C_{20}H_{24}N_2O$, crystallizes in small but beautifully brilliant, transparent four-sided prisms. It is but very feebly soluble in water, dissolves readily in boiling alcohol, and has but little taste, although its salts are excessively bitter. It is a powerful base, neutralizing acids completely, and forming a series of crystallizable salts. Cinchonine turns the plane of polarization to the right.

Quinine or *quinia*, $C_{20}H_{24}N_2O_2$, much resembles cinchonine; it does not crystallize so well, however, and is much more soluble in water; its taste is intensely bitter. Quinine turns the plane of polarization towards the left.

Quininic sulphate (sulphate of quinine) is manufactured on a very large scale for medicinal use. It crystallizes in small white needles, which give a neutral solution. It contains $2C_{20}H_{24}N_2O_2 \cdot H_2SO_4 \cdot 7H_2O$. Its solubility is much increased by the addition of a little sulphuric acid, whereby the acid salt, $C_{20}H_{24}N_2O_2 \cdot H_2SO_4 \cdot 7H_2O$, is formed. A very interesting compound has been produced by Dr. Herapath, by the action of iodine upon quininic sulphate. It is a crystalline substance of a brilliant emerald color, which appears to consist of equal equivalents of the sulphate of quinine and of iodine. This remarkable compound possesses the optical properties of the tourmaline, and is often called *artificial tourmaline*.

478. *Strychnine and Brucine*.—These alkaloids, also called *strychnia* and *brucia*, are contained, together with several still imperfectly known bases, in *Nux vomica*, in *St.*

Ignatius' bean, and in *false Angustura bark* (*Brucea antidysenterica*).

Pure strychnine crystallizes under favorable circumstances in small but exceedingly brilliant octohedral crystals, which are transparent and colorless. It has a very bitter, somewhat metallic taste (1 part in 1,000,000 parts of water is still perceptible), is slightly soluble in water, and fearfully poisonous. It dissolves in hot and somewhat dilute spirit, but not in absolute alcohol, ether, or solution of caustic alkali. This alkaloid may be readily identified by moistening a crystal with concentrated sulphuric acid, and adding to the liquid a crystal of potassic dichromate, when a deep violet tint is produced, which disappears after some time. Strychnine forms with acids a series of well-defined salts, and its formula is $C_{21}H_{22}N_2O_7$.

Brucine, $C_{23}H_{26}N_2O_6$, is easily distinguished from strychnine, which it much resembles in many respects, by its ready solubility in alcohol, both hydrated and absolute. It dissolves also in about 500 parts of hot water. The salts of brucine are, for the most part, crystallizable.

479. *Caffeine or Theine*. — This remarkable substance, $C_8H_{10}N_4O_2$, occurs in several articles of domestic life, infusions of which are used as beverages by three fourths of the human race; in tea and coffee, in *maté* (*Ilex Paraguayensis*), and in the leaves of *Paullinia sorbilis*. It will probably be found in other plants. A decoction of common tea, or of raw coffee-berries, previously crushed, is mixed with excess of solution of basic plumbic acetate. The solution, filtered from the copious yellow or greenish precipitate, is treated with hydric sulphide (sulphuretted hydrogen) to remove the lead, then filtered, evaporated to a small bulk, and neutralized by ammonia. The caffeine crystallizes out on cooling, and is easily purified by animal charcoal. It forms tufts of delicate, white, silky needles, which have a bitter taste, melt with loss of water when

heated, and sublime without decomposition. It is soluble in about 100 parts of cold water, and much more easily at the boiling heat, or if an acid be present. Alcohol also dissolves it, but not easily. The basic properties of caffeine are feeble. The salts which it forms with muriatic and sulphuric acids are obtained only with difficulty. It forms, however, splendid double salts with platinic tetrachloride and auric trichloride.

Tea, coffee, and the Paraguay tea-plant, in the form in which they are used as beverages, all contain, (1) *caffeine*, (2) one of the forms of *tannic acid*, and (3) an aromatic essential oil, which is different in each plant, and is the main cause of their different and peculiar flavors.

The coffee-berry contains about .8 of one per cent of free caffeine (and, according to Payen, about 1.5 per cent more in a peculiar salt); from 10 to 13 per cent of fixed oils; 15.5 per cent of gum, sugar, etc.; and only about .002 of one per cent of the aromatic oil to which it owes its distinctive flavor.

In tea, the amount of caffeine (or theine) ranges from 2 to 4 per cent, and that of the essential oil from .6 to .8 of one per cent. This oil exerts a very powerful stimulating and intoxicating effect. In China tea is seldom used until it is a year old, on account of the intoxicating effects of new tea, due probably to the larger proportion of oil in the freshly dried leaf. Tannin forms from 13 to 18 per cent of tea, while in coffee it averages about 5 per cent.

The use of coffee appears to exercise an important influence in retarding the waste of the animal tissues.

480. *Theobromine*. — The seeds of the *Theobroma Cacao*, or cacao-nuts, from which chocolate is prepared, contain a crystallizable principle, to which this name is given. It forms a white, crystalline powder, which is much less soluble than caffeine. It contains, according to Glasson, $C_7H_8N_4O_2$. Its basic properties are very feeble.

The cacao-nut, when deprived of its husk, contains nearly 56 per cent of fatty matter (which is remarkable for not being liable to become rancid), 17 per cent of a substance resembling gluten, 1.2 to 1.5 of theobromine, and 22 of starch, gum, sugar, and woody fibre. The aromatic flavor of cocoa is due to the *roasting* of the nut before grinding it.

481. *Nicotine*. — This base, also called *nicotylia*, C_5H_7N , is the active principle of the tobacco-plant (*Nicotiana tabacum*), in which it occurs combined with malic and citric acids. It is also found in the smoke of the burning leaves. It is a limpid, colorless, oily liquid, with an extremely irritating and powerful odor of tobacco. It is very inflammable, and burns with a smoky flame. Exposed to the air it absorbs oxygen, and turns brown. It is very soluble in water and in the fixed oils; also in alcohol and in ether. It is very poisonous, a single drop being sufficient to kill a large dog.

ORGANIC COLORING PRINCIPLES.

482. *Dyeing*. — The organic coloring principles are substances of great practical importance. With the exception of one red dye, *cochineal*, they are all of vegetable origin.

The art of *dyeing* is founded upon an affinity or attraction existing between the coloring matter of the dye and the fibre of the fabric. In wool and silk this affinity is usually very considerable, and to such tissues a permanent stain is very easily given; but with cotton and flax it is much weaker. Recourse is then had to a third substance, which does possess such affinity in a high degree, and with this the cloth is impregnated. Such substances are termed *mordants*. Alumina, ferric oxide, and stannic oxide are bodies of this class.

When an infusion of some dye-wood—as logwood, for ex-

ample—is mixed with alum and a little alkali, a precipitate falls, consisting of alumina in combination with coloring matter, called a *lake*. It is by the formation of this insoluble substance within the fibre that a permanent dyeing of the cloth is effected. Ferric oxide usually gives rise to dull, heavy colors; alumina and stannic oxide, especially the latter, to brilliant ones. It is easy to see that, by applying the mordant *partially* to the cloth, by a wood-block or otherwise, and then dyeing the whole cloth and washing it, a pattern may be produced, as the color will be removed from the other portions by the washing.

483. *Indigo*. — Indigo is the most important member of the group of blue coloring matters. It is the product of several species of the genus *Indigofera*, which grow principally in warm climates. When the leaves of these plants are placed in a vessel of water and allowed to ferment, a yellow substance is dissolved out, which by contact with air becomes deep-blue and insoluble, and finally precipitates. This, washed and carefully dried, constitutes the indigo of commerce. It is not contained ready formed in the plant, but is produced by the oxidation of some substance there present. Neither is the fermentation essential, as a mere infusion of the plant in hot water deposits indigo by standing in the air.

Indigo comes into the market in the form of cubic cakes, which, when rubbed with a hard body, exhibit a copper-red appearance; its powder has a deep-blue tint. The best indigo is so light as to float upon water. In addition to the blue coloring matter, or true indigo, it contains at least half its weight of various impurities, among which may be noticed a red resinous matter, the *indigo red* of Berzelius; these may be extracted by boiling the powdered indigo in dilute acid, in alkali, and afterwards in alcohol.

Pure indigo is quite insoluble in water, alcohol, oils, dilute acids, and alkalies. It dissolves in about 15 parts of

concentrated sulphuric acid, forming a deep-blue pasty mass, entirely soluble in water, and often used in dyeing. This is *sulphindyllic* or *sulphindigotic acid*, capable of forming with alkaline bases blue salts, which, though easily soluble in pure water, are insoluble in saline solutions. If an insufficient quantity of sulphuric acid has been employed, or the digestion not long enough continued, a purple powder is left on diluting the acid mass, soluble in a large quantity of pure water. The Nordhausen acid answers far better for dissolving indigo than ordinary oil of vitriol. Indigo may, by cautious management, be volatilized; it forms a fine purple vapor, which condenses in brilliant copper-colored needles.

In contact with deoxidizing agents, and with an alkali, indigo suffers a very curious change; it becomes soluble and nearly colorless, perhaps returning to the same state in which it existed in the plant. It is on this principle that the dyer prepares his *indigo-vat*: 5 parts of powdered indigo, 10 parts of green vitriol, 15 parts of slaked lime, and 60 parts of water, are agitated together in a close vessel, and then left to stand. The ferrous hydrate, in conjunction with the excess of lime, reduces the indigo to the soluble state; a yellowish liquid is produced, from which acids precipitate the *white* or *deoxidized* indigo as a flocculent insoluble substance, which absorbs oxygen with the greatest avidity, and becomes blue. Cloth, steeped in the alkaline liquid, and then exposed to the air, acquires a deep and most permanent blue tint by the deposition of solid insoluble indigo in the substance of the fibre. Instead of the iron salt and lime, a mixture of dilute caustic soda and grape-sugar dissolved in alcohol may be used; the sugar becomes oxidized to formic acid, and the indigo reduced. On allowing a solution of this description to remain in contact with the air, it absorbs oxygen, and deposits the indigo in the crystalline state.

The following are the formulæ of the compounds just described :—

Blue insoluble indigo	.	.	C_8H_5NO .
White or reduced indigo	.	.	$C_{16}H_{12}N_2O_2$.
Sulphindyllic acid	.	.	$C_8H_5NO \cdot SO_2$.

484. *Lichens*.—*Litmus* is used by the dyer as a red coloring matter ; the chemist employs it in the blue state as a test for the presence of acid, by which it is instantly reddened.*

Many lichens, when exposed in a moistened state to the action of ammonia, yield purple or blue coloring principles, which, like indigo, do not exist in the plant itself. Thus, the *Roccella tinctoria*, the *Variolaria orcina*, the *Lecanora tartarea*, etc., when ground to paste with water, mixed with solution of ammoniac carbonate, and left for some time freely exposed to the air, furnish the *archil*, *litmus*, and *cudbear* of commerce, very similar substances, differing chiefly in the details of the preparation. From these the coloring matter is easily extracted by water or very dilute solution of ammonia.

485. *Cochineal*.—This is a little insect,—the *Coccus cacti*,—which lives on several species of *cactus*, found in warm climates, and cultivated for the purpose, as in Central America. The dried body of the insect yields to water and alcohol a beautiful red coloring matter, precipitable by alumina and oxide of tin : *carmine* is a preparation of this kind. In cochineal the coloring matter is associated with several inorganic salts, especially phosphates,

* In preparing test-papers for chemical use with infusion of litmus, good writing or drawing paper, free from alum and other acid salts, should be chosen. Those sheets which after drying exhibit red spots, or patches, may be reddened completely by a little dilute acetic acid, and used, with much greater advantage than turmeric-paper, to discover the presence of free alkali, which restores the blue color.

and nitrogenous substances. Mr. Warren De La Rue, who has published a very elaborate investigation of cochineal, has separated the pure coloring matter, which he calls *carminic acid*. It is a purple-brown mass, yielding a fine red powder, soluble in water and alcohol in all proportions, slightly soluble in ether. It is soluble without decomposition in concentrated sulphuric acid, but readily attacked by chlorine, bromine, and iodine, which change its color to yellow. It resists a temperature of 136° , but is charred when heated more strongly. Carminic acid is a feeble acid. The composition of the substance, dried at 120° , is represented by $C_{14}H_{14}O_8$, which formula is corroborated by the analysis of a copper compound, $2C_{14}H_{14}O_8 \cdot CuO$.

By the action of nitric acid upon carminic acid, there is formed, together with oxalic acid, a splendid nitrogenous acid, crystallizing in yellow rhombic plates. This substance, to which the name *nitrococcusic acid* is given, is dibasic; it contains $H_2 \cdot C_8H_3N_3O_9$. It is soluble in cold, more so in boiling water, and readily soluble in alcohol and ether. Nitrococcusic acid is evidently derived from a non-nitrogenous compound in which part of the hydrogen is replaced by NO_2 . Like all substances of this class, it explodes when heated.

486. *Madder*. — The root of the *Rubia tinctorum*, cultivated in Southern France, the Levant, etc., is the most permanent and valuable of the red dye-stuffs. In addition to several yellow coloring matters, which are of little importance for the purposes of the dyer, madder contains two red pigments, which are called *alizarine* and *purpurine*.

The beautiful *Turkey red* of cotton cloth is a madder color; it is given by a very complicated process, the theory of which is not yet perfectly elucidated.

487. *Safflower*. — This substance contains a yellow and a red coloring matter, the latter being insoluble in water, but soluble in alkaline liquids. In its purest form the yel-

low matter constitutes a deep yellow, uncrystallizable, and very soluble substance, very prone to oxidation.

The red matter, or *carthamine*, forms, when pure and dry, an amorphous, brilliant green powder, nearly insoluble in water, but soluble in alcohol with splendid purple color.

488. *Other Dyes.* — *Brazil-wood* and *logwood* give red and purple infusions, which are largely used in dyeing; the coloring principle of logwood is termed *hematoxylene*, and has been obtained in crystals. Acids brighten these colors, and alkalies render them purple or blue.

Among yellow dyes, *quercitron bark*, *fustic-wood*, and *saffron* may be mentioned, and also *turmeric*; these all give yellow infusions to water, and furnish more or less permanent colors.

CYANOGEN COMPOUNDS.

489. *Cyanogen.* — If in a molecule of marsh gas, CH_4 , three atoms of H be replaced by the triad atom N, we have CHN , or, as it is usually written, HCN . This compound is called *prussic* or *hydrocyanic acid*. The H may be withdrawn from it, leaving the univalent radical CN, called *cyanogen*.

Cyanogen is a negative radical, analogous to chlorine, bromine, and iodine. Its compounds with metals and other positive radicals are called *cyanides*; as, —

Hydric cyanide, or hydrocyanic acid	HCN
Potassic cyanide	KCN
Ethyllic cyanide	$\text{C}_2\text{H}_5\text{CN}$
Baric cyanide	$\text{Ba}^+(\text{CN})_2$

Cyanogen, in its capacity of a quasi-element, is often represented by the symbol Cy.

Cyanogen in the free state, C_2N_2 , or $\text{N}=\text{C}-\text{C}=\text{N}$, may be

obtained by decomposing certain metallic cyanides. Pulverized and well-dried mercuric cyanide, $\text{Hg}^2(\text{CN})_2$, heated in a small retort of hard glass, undergoes decomposition, like the oxide under similar circumstances, yielding metallic mercury and cyanogen, a colorless, permanent gas, which must be collected over mercury. It has a pungent and very peculiar odor, remotely resembling that of peach-kernels, or hydrocyanic acid. Exposed at the temperature of 45°F. (7.2°C.) to a pressure of 3.6 atmospheres, it condenses to a thin, colorless, transparent liquid. Cyanogen is inflammable; it burns with a beautiful purple or peach-blossom-colored flame, generating carbonic anhydride, and liberating nitrogen. The specific gravity of this gas is 1.806.

490. *Paracyanogen*. — This is a brown or blackish substance which is always formed in small quantity when cyanogen is prepared by heating mercuric cyanide, and probably, also, by the decomposition of solutions of cyanogen and of hydrocyanic acid. It is insoluble in water and alcohol, is dissipated by a very high temperature, and contains, according to Johnston, carbon and nitrogen in the same proportion as cyanogen.

491. *Hydric Cyanide (Hydrocyanic or Prussic Acid)*. — This very important compound, so remarkable for its poisonous properties, was discovered as early as 1782 by Scheele. The pure acid is a thin, colorless, and exceedingly volatile liquid, which has a density of 0.7058 at 7.2° , boils at 26.1° , and solidifies when cooled to -18° . Its odor is very powerful and most characteristic, much resembling that of peach-blossoms or bitter-almond oil; it has a very feeble acid reaction, and mixes with water and alcohol in all proportions. In the anhydrous state this substance constitutes one of the most formidable poisons known, and even when largely diluted with water its effects upon the animal system are exceedingly energetic;

it is employed, however, in medicine, in very small doses. The inhalation of the vapor should be carefully avoided in all experiments in which hydrocyanic acid is concerned, as it produces headache, giddiness, and other disagreeable symptoms: ammonia and chlorine are the best antidotes.

The acid in its pure form can scarcely be preserved. Even when put in a carefully stopped bottle, it soon darkens and eventually deposits a black substance containing carbon, nitrogen, and perhaps hydrogen; ammonia is formed at the same time, and many other products. Light favors this decomposition. Even in a dilute condition it is apt to decompose, becoming brown and turbid.

492. *Potassic Cyanide*. — Potassium heated in cyanogen gas takes fire and burns in a very beautiful manner, yielding potassic cyanide, KCN or KCy. The same substance is produced when potassium is heated in the vapor of hydrocyanic acid, hydrogen being liberated.

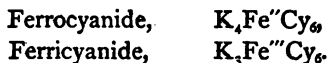
Potassic cyanide forms colorless cubic or octohedral crystals, deliquescent in the air, and exceedingly soluble in water; it dissolves in boiling alcohol, but separates in great measure on cooling. It is readily fusible, and undergoes no change at a moderate red or even white heat, when excluded from air; otherwise, oxygen is absorbed and the cyanide becomes cyanate. Its solution always has an alkaline reaction, and when exposed to the air exhales the odor of hydrocyanic acid; it is decomposed by the feeblest acids, even the carbonic acid of the atmosphere. It is said to be as poisonous as hydrocyanic acid itself.

493. *Mercuric Cyanide*. — One of the most remarkable properties of cyanogen is its powerful attraction for certain of the less oxidizable metals, as silver, and more particularly for mercury and palladium. Dilute hydrocyanic acid dissolves finely powdered mercuric oxide with the utmost

ease; the liquid loses all odor, and yields, on evaporation, crystals of mercuric cyanide, $\text{Hg}''\text{Cy}_2$. Potassic cyanide is in like manner decomposed by mercuric oxide, potassic hydrate being produced. Mercuric cyanide forms white, translucent prisms, much resembling those of corrosive sublimate. It is soluble in 8 parts of cold water, and in a much smaller quantity of hot water, and also in alcohol. The solution has a disagreeable metallic taste, is very poisonous, and is not precipitated by alkalies. Mercuric cyanide is used in the laboratory as a source of cyanogen.

494. *Iron Cyanides*. — These compounds are scarcely known in the separate state, on account of their great tendency to form double salts.

They unite with other metallic cyanides, forming two very important groups of compounds, called *ferrocyanides* and *ferricyanides*, the composition of which may be illustrated by the respective potassium-salts: —



It will be seen from these formulæ that the ferro- and ferricyanides differ from one another only by one atom of univalent metal; and, accordingly, it is found that the former may be converted into the latter by the action of *oxidizing* (metal-abstracting) agents, and the latter into the former by the action of *reducing* (metal-adding) agents.

495. *Potassic Ferrocyanide*. — This salt, $\text{K}_4\text{Fe}''\text{Cy}_6$, is commonly called *yellow prussiate of potash*. It is manufactured on the large scale by the following process: Dry refuse animal matter of any kind is fused at a red heat with impure potassic carbonate and iron filings in a large iron vessel, from which the air should be excluded as much as possible; potassic cyanide is generated in large quantity. The melted mass is afterwards treated with hot water, which dissolves out the cyanide and other salts, the

cyanide being quickly converted by the oxide or sulphide* of iron into ferrocyanide. The filtered solution is evaporated, and the first-formed crystals are purified by re-solution. If a sufficient quantity of iron be not present, great loss is incurred by the decomposition of the cyanide into potassic carbonate and ammonia.

Potassic ferrocyanide forms large, transparent, yellow crystals, $K_4Fe''Cy_6 \cdot 3H_2O$, derived from an octohedron with a square base; they are tough and difficult to powder. They dissolve in 4 parts of cold and 2 parts of boiling water, and are insoluble in alcohol. They are permanent in the air, and have a mild saline taste. The salt has no poisonous properties.

Potassic ferrocyanide is a chemical reagent of great value; when mixed in solution with neutral or slightly acid salts of the heavy metals, it gives rise to precipitates which very frequently present highly characteristic colors. In most of these compounds the potassium is simply displaced by the new metal; the beautiful brown ferrocyanide of copper contains, for example, $Cu''_2Fe''Cy_6$, or $2Cu''Cy_2 \cdot Fe''Cy_2$, and that of lead, $Pb''_2Fe''Cy_6$.

With *ferrous salts*, potassic ferrocyanide gives a precipitate which is perfectly white, if the air be excluded and the solution is quite free from ferric salt, but quickly turns blue on exposure to the air. It consists of *potassio-ferrous ferrocyanide*, $K_2Fe''Cy_6$, or potassic ferrocyanide having half the potassium replaced by iron.

496. *Prussian Blue*. — When a soluble ferrocyanide is added to the solution of a *ferric salt*, a deep-blue precipitate is formed, consisting of *ferric ferrocyanide*, $Fe'''_4Fe''Cy_{12}$, which in combination with 18 molecules of water constitutes ordinary Prussian blue.

Prussian blue in the moist state forms a bulky precipi-

* The sulphur is derived from the reduced sulphate of the crude pearl-ashes and the animal substances used in the manufacture.

tate, which shrinks to a comparatively small compass when well washed and dried by a gentle heat. In the dry state it is hard and brittle, much resembling in appearance the best indigo; the freshly fractured surfaces have a beautiful copper-red lustre, similar to that produced by rubbing indigo with a hard body. Prussian blue is quite insoluble in water and dilute acids, with the exception of oxalic acid, in a solution of which it dissolves, forming a deep-blue liquid, which is sometimes used as ink. It forms a very beautiful pigment, but has little permanency.

497. *Ferricyanides*.—These salts are formed, as already observed, by abstraction of metal from the ferrocyanides; in other words, by the action of oxidizing agents.

Potassic ferricyanide, $K_3Fe^{III}Cy_6$, often called *red prussiate of potash*, forms regular prismatic, or sometimes tabular crystals, of a beautiful ruby-red tint, permanent in the air, and soluble in 4 parts of cold water; the solution has a dark-greenish color. The crystals burn when introduced into the flame of a candle, and emit sparks.

Potassic ferricyanide, added to a ferric salt, occasions no precipitate, but merely a darkening of the reddish-brown color of the solution; with *ferrous salts*, on the other hand, it gives a deep-blue precipitate, consisting of *ferrous ferricyanide*, $Fe^{II}_3Fe^{III}_2Cy_{12}$, which, when dry, has a brighter tint than Prussian blue: it is known under the name of *Turnbull's blue*. Hence, potassic ferricyanide is as delicate a test for ferrous salts as the yellow ferrocyanide is for ferric salts.

498. *Cobalticyanides*.—This name is applied to a series of compounds analogous to the preceding, containing cobalt in place of iron: a hydrogen acid has been obtained, and a number of salts, which much resemble the ferricyanides. Several other metals of the same family are found capable of replacing iron in these compounds.

499. *Nitroprussides*. — The action of nitric acid upon ferrocyanides and ferricyanides gives rise to the formation of a very interesting series of new salts, which were discovered by Dr. Playfair. The general formula of these salts appears to be $M_2(NO)Fe''Cy_2$, which exhibits a close relation with those of the ferro- and ferricyanides.

500. *Cyanic and Cyanuric Acids*. — These are two remarkable bodies, related in a very close and intimate manner, and presenting phenomena of great interest. Cyanic acid is formed as a potassium salt, in conjunction with potassic cyanide, when cyanogen gas is transmitted over heated potassic hydrate or carbonate, or passed into a solution of the alkaline base; the reaction resembling that by which potassic chlorate and potassic chloride are generated when chlorine is passed into a solution of potash (105). Potassic cyanate is, moreover, formed when the cyanide is exposed to a high temperature with access of air: unlike the chlorate, it bears a full red heat without decomposition.

Cyanic acid, $HCNO$, is a limpid, colorless liquid, of exceedingly pungent and penetrating odor, like that of the strongest acetic acid; it even blisters the skin. When mixed with water, it decomposes almost immediately.

Shortly after its preparation it changes spontaneously, with sudden elevation of temperature, into a solid, white, opaque, amorphous substance, called *cyamelide*, which has the same composition as cyanic acid, and by dry distillation is again converted into that acid.

Cyanuric acid, $H_3C_3N_3O_3$, forms colorless efflorescent crystals, seldom of large size, derived from an oblique rhombic prism. It is very little soluble in cold water, and requires 24 parts for solution at a boiling heat; it reddens litmus feebly, has no odor, and but little taste. The acid is tribasic; the crystals contain $H_3C_3N_3O_3 \cdot 2H_2O$, and are easily deprived of their water of crystallization.

In point of stability, cyanuric acid offers a most remarkable contrast to its isomer, cyanic acid; it dissolves in hot oil of vitriol, without decomposition, and, in fact, crystallizes from the latter in the anhydrous state. Long-continued boiling with these powerful agents resolves it into ammonia and carbonic acid.

501. *Fulminic Acid*. — This remarkable compound, $\text{H}_2\text{C}_2\text{N}_2\text{O}_2$, originates in the peculiar action exercised by nitrous acid upon alcohol in presence of a salt of silver or mercury. The acid itself, or hydric fulminate, has not been obtained.

Argentie fulminate is obtained in the form of small, brilliant, white crystalline plates. The only perfectly safe method of keeping the salt is by immersing it in water. It is soluble in 36 parts of boiling water, but the greater part crystallizes out on cooling. It is one of the most dangerous substances known, exploding with fearful violence when strongly heated, or when rubbed or struck with a hard body, or when touched with concentrated sulphuric acid; the metal is reduced, and a large volume of gaseous matter suddenly liberated. Strange to say, it may, when very cautiously mixed with cupric oxide, be burned in a tube with as much facility as any other organic substance. Its composition, thus determined, is expressed by the formula $\text{Ag}_2\text{C}_2\text{N}_2\text{O}_2$.

Fulminic acid is dibasic: when argentic fulminate is digested with caustic potash, one half of the silver is precipitated as oxide, and an *argento-potassic fulminate*, $\text{AgKC}_2\text{N}_2\text{O}_2$, is produced, which resembles the silver-salt, and detonates by a blow. *Mercuric fulminate*, $\text{Hg}^{\text{II}}\text{C}_2\text{N}_2\text{O}_2$, resembles the silver-salt in appearance, properties, and degree of solubility. It explodes violently by friction or percussion, but, unlike the silver compound, merely burns with a sudden and almost noiseless flash when kindled in the open air. It is manufactured on a large scale for the

purpose of charging *percussion-caps*; sulphur and potassic chlorate, or more frequently nitre, are added, and the powder, pressed into the cap, is secured by a drop of varnish.

The relations of the three isomeric acids, cyanic, fulminic, and cyanuric, are beautifully seen by comparing their silver-salts: the first acid is monobasic, the second dibasic, and the third tribasic:—

Argenticyanate	AgCNO .
“ fulminate	$\text{Ag}_2\text{C}_2\text{N}_2\text{O}_2$.
“ cyanurate	$\text{Ag}_3\text{C}_3\text{N}_3\text{O}_3$.

502. *Sulphocyanic Acid, etc.*—This acid, HCNS , is the sulphur analogue of cyanic acid, and, like the latter, is monobasic, the Sulphocyanates of monad metals being represented by the formula MCNS .

Potassic sulphocyanate, KCNS , crystallizes in long, slender, colorless prisms, or plates, which are anhydrous; it has a bitter saline taste, and is destitute of poisonous properties; it is very soluble in water and alcohol, and deliquesces when exposed to a moist atmosphere. When heated, it melts to a colorless liquid at a temperature far below that of ignition.

A soluble sulphocyanate mixed with a ferric salt gives no precipitate, but causes the liquid to assume a deep blood-red tint: hence the use of potassic sulphocyanate as a test for iron in the state of ferric salt.

FERMENTATION.

503. *Causes of Fermentation.*—Complex organic compounds are often broken up into simpler compounds by the agency of growing plants. This process is called *fermentation*, and the organisms which effect it are called *ferments*. Different ferments give rise to different products, as alco-

hol, vinegar, etc. Most of these ferments are plants, but one at least is an animal ; and this, strange to say, cannot live in contact with free oxygen, but flourishes in an atmosphere of hydrogen. In order that the ferment should grow, it must be supplied with proper food, especially with ammoniacal salts and alkaline phosphates. These are contained in the albuminous matter generally present in the liquid about to be fermented. In order that the fermentation should go on well, the temperature should be from 21° (70° F.) to 38° (100° F.) ; at much higher, as at much lower temperatures, the vitality of the ferment is destroyed.

In many cases, spontaneous fermentation sets in without the apparent addition of any ferment : thus wine, beer, milk, etc., when allowed simply to stand exposed to the air, become sour or otherwise decompose. These changes are, however, not effected without the presence of vegetable or animal life, and are true fermentations. The *sporules*, or seeds of these living bodies, are always floating in the air, and on dropping into the liquid begin to propagate themselves, and in the act of growing evolve the products of the fermentation. If the liquid be left only in contact with air which has been passed through a red-hot platinum tube, so that the living sporules are destroyed ; or if the air be simply filtered by passing through cotton-wool, so that the sporules are prevented from coming into the liquid, — it is found that the liquid may be preserved for any length of time without undergoing the slightest change.

The principal forms of fermentation are : —

(1.) The *alcoholic* fermentation, producing chiefly alcohol and carbonic anhydride.

(2.) The *lactic* fermentation, producing acetic acid.

304. *Alcoholic Fermentation*. — Grape-sugar, if dissolved in presence of yeast (which is a plant and a ferment),

undergoes fermentation, evolving mainly alcohol and carbonic anhydride :—



If cane-sugar be used, it is first converted into grape-sugar by taking up water ($C_{12}H_{22}O_{11} + H_2O = 2C_6H_{12}O_6$) and the latter is then decomposed as above.

About 6 per cent of the sugar undergoes a different change, part being used as nourishment for the yeast, and part forming glycerine and other compounds. The alcoholic fermentation is best effected at a temperature between 25° (77° F.) and 30° (86° F.).

When the cereal grains are used for making alcohol, the starch of the grain is first converted into sugar. This change may be brought about by the action of sulphuric acid, as already explained (446); but, practically, it is usually effected by means of *diastase*.

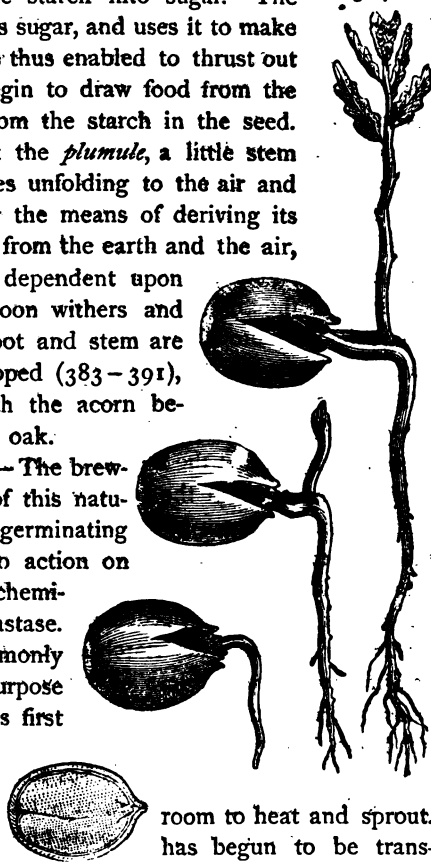
505. *The Formation of Diastase in Growing Plants.*—We have learned that the seed contains a supply of starch, which is the food of the embryo plant until it is able to derive its sustenance from the earth and the air. We have learned, too, that this starch must be converted into sugar, in order that it may be dissolved in the sap of the plant and carried where it is needed for the purposes of growth. Let us now see how the starch is changed to sugar. The seed contains more or less of the *nitrogenized* compound, *gluten* (380). This, under the influence of heat and moisture, begins to putrefy, and a portion of it is converted into the ferment *diastase*. This has so powerful an action upon starch, that 1 part of it, at a temperature of 65.5°, is sufficient to convert 2,000 parts of starch into dextrine and then into sugar.

We can now understand how a seed, like the acorn (Figure 67), germinates. If we cut the acorn open we see the *radicle* (at the right in the figure), and the two thick

cotyledons, or seed-leaves, containing the starch and gluten. In the moist, warm soil the acorn absorbs a little water, and the gluten is thus changed into diastase, which converts some of the starch into sugar. The radicle absorbs this sugar, and uses it to make woody fibre. It is thus enabled to thrust out a little root and begin to draw food from the earth, as well as from the starch in the seed. It next sends out the *plumule*, a little stem with its first leaves unfolding to the air and light. It has now the means of deriving its nourishment both from the earth and the air, and is no longer dependent upon the seed, which soon withers and perishes. Both root and stem are now rapidly developed (383-391), and thus at length the acorn becomes the mighty oak.

506. *Brewing*.—The brewer avails himself of this natural change in the germinating seed, and calls into action on a larger scale the chemical influence of diastase. The grain commonly used for the purpose is barley. This is first moistened in heaps, and spread out in a dark room to heat and sprout. When the gluten has begun to be transformed into diastase and the starch into sugar, so that the germ is about to burst from the envelop of the seed, the growth is arrested by heating the grain, and thus killing the embryo plant.

Fig. 67.



The *malt*, as the barley is now called, is next bruised, and soaked in warm water in the *mash-tub*. The water dissolves first the sugar which has already been formed in the seed, and then the diastase. The latter acts upon the rest of the starch of the seed and of any raw grain which may be added to the malt, converting it into sugar, so that little, except the husk of the grain, is left undissolved; and the liquor, or *wort*, has a decidedly sweet taste.

The wort is now heated to boiling, to stop the action of the diastase, and to coagulate the albumen which has been dissolved out of the grain. At the same time, hops are added to the wort; and these, besides giving a bitter aroma to the liquid, help to clarify it. The boiled liquor is then filtered, and drawn off into shallow vessels, where it is cooled down to about 16° (60° F.). Yeast is now added, and the mixture is allowed to ferment for six or eight days.

This fermentation is never allowed to continue until all the sugar is converted into alcohol. From one half to three fourths of it is decomposed; and the rest is left to give a sweet taste to the beer, and also to keep it from souring in the cask.

The liquor is next put into casks, where it goes through a second and much slower fermentation, which is essential to its preservation. When this fermentation is completed, the cask must be closed tight to exclude the air, the oxygen of which would cause *acetous* fermentation. During this second fermentation the carbonic acid is generated, to which the liquor owes its sparkling *effervescent* character.

507. *The Distillation of Spirits.* — When fermented liquors are boiled, the alcohol they contain rises in the form of vapor, mingled with steam. If the boiling be performed in a close vessel, and the vapors be led by a pipe into a cold receiver, they condense into a liquid containing a considerable percentage of alcohol.

We have seen that, in making beer, the fermentation of

the wort is checked before all the sugar is converted into alcohol. But in the manufacture of spirits from grain the fermentation is prolonged until all the sugar is transformed into alcohol and carbonic acid. To leave any of it unchanged would not only involve a loss of spirit, but, during the subsequent distillation, might injure the flavor of the spirit obtained.

508. *Alcohol (Ethylic Alcohol)*.—The spirit first obtained by distilling a fermented saccharine liquid is very weak, being diluted with a large quantity of water. By a second distillation, in which the first portions of the distilled liquid are collected apart, it may be greatly strengthened; the whole of the water cannot, however, be thus removed. The strongest rectified alcohol of commerce has a density of about 0.835, and yet contains 13 or 14 per cent of water. Pure or *absolute* alcohol may be obtained from it by redistilling it with calcic chloride or with quicklime.

Pure alcohol, $C_2H_5 \cdot HO$, is a colorless, limpid liquid, of pungent and agreeable taste and odor; its specific gravity, at $15.5^\circ C.$ ($60^\circ F.$), is 0.7938, and that of its vapor referred to air, 1.613. It is very inflammable, burning with a pale-bluish flame, free from smoke; it has never been frozen. Alcohol boils at $78.4^\circ C.$ ($173^\circ F.$) when in the anhydrous state; in a diluted state the boiling-point is higher, being progressively raised by each addition of water. In the act of dilution a contraction of volume occurs, and the temperature of the mixture rises many degrees; this takes place not only with pure alcohol, but also with rectified spirit. Alcohol mixes with water in all proportions, and, indeed, has a great attraction for the latter, absorbing its vapor from the air, and abstracting the moisture from membranes and other similar substances immersed in it. The solvent powers of alcohol are very extensive; it dissolves a great number of saline compounds, and likewise a considerable proportion of potash.

Wine, beer, etc. owe their intoxicating properties to the alcohol they contain, the quantity of which varies very much. Port and sherry, and some other strong wines, contain, according to Mr. Brande, from 19 to 25 per cent of alcohol, while in the lighter wines of France and Germany it sometimes falls as low as 12 per cent. Strong ale contains about 10 per cent; ordinary spirits, as brandy, gin, whiskey, 40 to 50 per cent, or occasionally more. These latter owe their characteristic flavors to certain essential oils, present in very small quantity, either generated in the act of fermentation or purposely added.

509. *Wine.* — In making wine the expressed juice of the grape is simply set aside in large vats, where it undergoes spontaneously the necessary change. The vegetable albumen of the juice absorbs oxygen from the air, decomposes, and becomes a ferment to the sugar, which is gradually converted into alcohol. If the sugar be in excess, and the nitrogenized matter deficient, the resulting wine remains sweet; but if, on the other hand, the proportion of sugar be small and that of albumen large, a *dry* wine is produced. When the fermentation stops, and the liquor becomes clear, it is drawn off from the lees, and transferred to casks, to ripen and improve.

The color of red wine is derived from the skins of the grapes, which in such cases are left in the fermenting liquid. Effervescent wines, as champagne, are bottled before the fermentation is complete; the carbonic acid is disengaged under pressure, and retained in solution in the liquid. A certain quantity of sugar is frequently added. The process requires much delicate management.

During the fermentation of the grape-juice, or *must*, a crystalline, stony matter, called *argol*, is deposited. This consists chiefly of acid potassic tartrate with a little coloring matter, and is the source of all the tartaric acid met with in commerce. This salt exists in the juice in consid-

erable quantity ; it is but sparingly soluble in water, but still less so in dilute alcohol ; hence, as the fermentation proceeds, and the quantity of spirit increases, it is slowly deposited. The acid of the juice is thus removed as the sugar disappears. It is this circumstance which renders grape-juice alone fit for making good wine ; when that of gooseberries or currants is employed as a substitute, the malic and citric acids which these fruits contain cannot be thus withdrawn. There is then no other resource but to add sugar in sufficient quantity to mask and conceal the natural acidity of the liquor. Such wines are necessarily acescent and prone to a second fermentation.

510. *Bread-Making.* — The making of bread in the ordinary way, by means of leaven or yeast, is an example of alcoholic fermentation.

When the grain of wheat is ground in a mill, and then sifted, it is separated into two parts, the *bran* and the *flour*. The bran is the outside harder part of the grain, which is not ground so readily, and, when ground, makes the flour darker. Both the bran and the flour consist mainly of gluten, starch, and water.

If the flour be mixed with water enough to moisten it thoroughly, the particles cohere and form a *dough*, which can be kneaded or moulded with the hand. It is the gluten of the flour which gives the tenacity to the dough.

A little leaven or yeast is added to the flour, either before it is mixed with water into a dough or in the course of this process ; and the dough is then placed for some hours in a warm atmosphere, in order that it may *rise*. This rising is a fermentation, caused by the leaven or yeast. Leaven is the primitive ferment, and is simply a piece of moistened dough which has begun to putrefy. When brought in contact with a fresh portion of flour and water, it very quickly acts as a ferment, and develops fer-

mentation in the whole mass. Yeast, as has been stated, is one of the vegetable growths which are ferments.

The leaven or yeast soon begins to act on the gluten, starch, and sugar of the flour, and a portion of the sugar is converted into carbonic acid and alcohol in every part of the dough. The bubbles of gas, thus disengaged in the mass, form innumerable cavities, and make it light and porous.

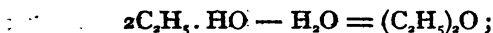
The spongy dough is now put into a hot oven, where the fermentation and swelling are at first increased by the heat; but when the whole has been heated to about 100° , the fermentation is suddenly arrested, and the mass becomes fixed in the form it has then attained. In the baking, some of the water is dissipated from the dough, the starch and gluten are partially *boiled*, and some of the starch is converted into dextrine. The brown, glossy appearance of the crust is due to this formation of dextrine (452). Most of the alcohol is driven off by the heat; but a large amount of water (about 45 per cent of the weight of the bread) remains in the loaf after the baking.

There are various methods of making bread without fermentation, most of which depend on the liberation of carbonic acid from one of its compounds, by means of an acid. Bicarbonate of soda and muriatic acid are the materials sometimes used. Cream of tartar, which is a compound of tartaric acid (462), is often used as the acid. The salt and acid are usually mixed with the dough, and the carbonic acid there set free; but in the manufacture of the so-called *aerated bread*, either water charged with the gas is used in making the dough,* or the gas itself is forced into the dough.

* This is the English method, which is thus described in Fownes's "Chemistry" (10th edition, London, 1868):—

"Another mode of bread-making, now practised on a large scale with great success, consists in agitating the dough in a strong vessel—

511. *Ethylic Ether*. — This compound, $(C_2H_5)_2O$, also called *ethylic oxide*, *common ether*, or simply *ether*, contains the elements of two molecules of alcohol *minus* 1 molecule of water : —



and it is in fact produced by the action of various *dehydrating* agents, such as zincic chloride, phosphoric oxide, and strong sulphuric acid, upon alcohol. The process does not appear, however, to be one of direct dehydration, at least in the case of sulphuric acid; for when that acid is heated with alcohol to a certain temperature it does not become weaker by taking water from the alcohol, but ether and water distil over together, and the sulphuric acid remains in its original state, ready to act in the same manner on a fresh portion of alcohol.

The most favorable temperature for etherification is between 127° and 154° C. (260° and 310° F.): below 127° very little ether is produced, and above 154° a different reaction takes place, resulting in the formation of olefiant gas. The maintenance of the temperature within the ether-producing limits is best effected by boiling the mixture of sulphuric acid and alcohol in a flask into which a further quantity of alcohol is supplied in a continuous and regulated stream. This is called the *continuous* ether process.

Pure ethylic ether is a colorless, transparent, fragrant liquid, very thin and mobile. Its sp. gr. at 15.5° is about 0.720; it boils at 35.6° C. (96° F.) under the pressure of the atmosphere, and bears, without freezing, the severest

with water saturated under pressure with carbonic acid gas. When the dough thus treated is subsequently released from this pressure and exposed to the air, the gas escapes in bubbles, and lightens the mass as effectually as that evolved within its substance by fermentation. The bread thus made, called *aerated bread*, is of excellent quality, not being subject to the deterioration which so frequently takes place in ordinary bread, when the fermentation is allowed to go too far."

gold. When dropped on the hand, it occasions a sharp sensation of cold, from its rapid volatilization. Ether is very combustible, and burns with a white flame, generating water and carbonic anhydride. Although the substance itself is one of the lightest of liquids, its vapor is very heavy, having a density of 2.586 (referred to air); it forms explosive mixtures with air or oxygen. Preserved in an imperfectly stopped vessel, ether absorbs oxygen, and becomes acid from the production of acetic acid; this attraction for oxygen is increased by elevation of temperature.

Ether mixes with alcohol in all proportions, but not with water; it dissolves to a small extent in that liquid, 10 parts of water taking up about 1 part of ether. It may be separated from alcohol, provided the quantity of the latter is not excessive, by addition of water, and in this manner samples of commercial ether may be conveniently examined. Ether dissolves oils, fats, and resins far more readily than alcohol does. It also dissolves sulphur, phosphorus, and iodine. When inhaled in sufficient quantity its vapor is an *anæsthetic*, and was the first substance used for that purpose by physicians.

512. *Acetic Acid*. — If alcohol, diluted with water, be mixed with a ferment, as yeast, and exposed to the air at ordinary temperatures, it is soon converted into *acetic acid*, or *vinegar*. The alcohol absorbs 2 atoms of oxygen, forming water and acetic acid: —



This process constitutes what is commonly called the *acetous fermentation*. Since the alcohol is oxidized, it is in a certain sense a *combustion* that takes place. It is, however, brought about by the influence of a ferment, known as the *vinegar-plant*, or *mother of vinegar*.

There are a great many methods of making vinegar on

the large scale ; but, for the most part, they are only different devices for exposing to the air as large a surface as possible of the alcoholic mixture. In one process, the liquid is allowed to trickle down through vats, filled with flat pieces of wicker-work, piled one upon another. These are first watered with vinegar, or liquid partially converted into vinegar, and thus become covered with the germs of the vinegar-plant. Air is admitted through holes in the bottom of the vats, and passes out at the top, after giving up a part of its oxygen to the alcohol. Heat is produced by the oxidation, and this causes an upward draft, and quickens the circulation of air through the vats.

In another process, the weak alcoholic liquor trickles down through perforated casks, filled with beech shavings, which have been thoroughly scalded to remove all soluble matter. Air is admitted by holes around the lower part of the cask, and passes out at the top.

When vinegar is purified, and concentrated by distillation, it constitutes the *acetic acid* of commerce. This is prepared on a large scale from *pyroligneous acid*, or *wood-vinegar*, which is obtained by the destructive distillation of wood (398).

The strongest acetic acid is prepared by distilling finely powdered anhydrous sodic acetate with three times its weight of concentrated oil of vitriol. The liquid is purified by rectification from sodic sulphate accidentally thrown up, and is exposed to a low temperature. Crystals of pure acetic acid then form in large quantity ; they may be drained from the weaker fluid portion, and suffered to melt. Below 15.5° this substance, often called *glacial acetic acid*, forms large, colorless, transparent crystals, which above that temperature fuse to a thin, colorless liquid, of exceedingly pungent and well-known odor ; it raises blisters on the skin. It mixes in all proportions with water, alcohol, and

ether, and dissolves camphor and several resins. When diluted, it has a pleasant acid taste. Glacial acetic acid in the liquid state has a density of 1.063, and boils at 120° . Its vapor is inflammable.

513. *Acetates*. — Acetic acid forms a large number of important salts, which are represented by the formulæ, $MC_2H_3O_2$, $M''(C_2H_3O_2)_n$, or $M'''(C_2H_3O_2)_3$, according to the equivalent value of the metals contained in them. Being a monobasic acid, it cannot form any acid salts properly so called, that is by replacement of a *part* of its hydrogen; but the normal acetates of the alkali metals can take up a molecule of acetic acid, just as they take up water of crystallization, forming salts called *acid acetates* or *diacetates*, $MC_2H_3O_2 \cdot C_2H_3O_2$. There are also basic acetates formed by the union of a molecule of a normal acetate with a molecule of metallic oxide or hydrate.

Sodic acetate, $NaC_2H_3O_2 \cdot 3H_2O$, forms large, transparent, colorless crystals, derived from a rhombic prism, which are easily rendered anhydrous by heat, effloresce in dry air, and dissolve in 3 parts of cold and in an equal weight of hot water; they are also soluble in alcohol. The taste of this salt is cooling and saline.

Aluminic acetate is very soluble in water, and dries up in the vacuum of the air-pump to a gummy mass without trace of crystallization. It is much used in calico-printing; it is prepared by mixing solutions of plumbic acetate and alum, and filtering from the insoluble plumbic sulphate. The liquid is thickened with gum or other suitable material, and with it the design is impressed upon the cloth by a wood-block, or by other means. Exposure to a moderate degree of heat drives off the acetic acid, and leaves the alumina in a state capable of entering into combination with the dye-stuff.

Ferrous acetate crystallizes in small, greenish-white needles, very prone to oxidation; both salts dissolve freely.

in water. *Ferric acetate* is a dark brownish-red, uncrystallizable liquid, of powerful astringent taste. Both these salts are used as mordants.

Plumbic acetate, $\text{Pb}(\text{C}_2\text{H}_3\text{O}_2)_2 \cdot 3\text{H}_2\text{O}$, is prepared on a large scale by dissolving litharge in acetic acid; it may be obtained in colorless, transparent, prismatic crystals, but is generally met with in commerce as a confusedly crystalline mass, somewhat resembling loaf-sugar. From this circumstance, and from its sweet taste, it is often called *sugar of lead*. The crystals are soluble in about $1\frac{1}{4}$ parts of cold water, effloresce in dry air, and when gently heated melt in their water of crystallization; the latter is easily driven off, and the anhydrous salt obtained, which melts, and afterwards decomposes, at a high temperature. The aqueous solution has an intensely sweet and at the same time astringent taste, and is not precipitated by ammonia. This salt is of great value to the chemist, and is much used in medicine and in the arts.

Common *verdigris* is a mixture of several basic cupric acetates which have a green or blue color. The *normal cupric acetate*, $\text{Cu}(\text{C}_2\text{H}_3\text{O}_2)_2 \cdot \text{H}_2\text{O}$, is prepared by dissolving *verdigris* in hot acetic acid, and leaving the filtered solution to cool. It forms beautiful dark-green crystals, which dissolve in 14 parts of cold and 5 parts of boiling water, and are also soluble in alcohol. A solution of this salt, mixed with sugar and heated, yields cupric oxide in the form of minute red octohedral crystals; the residual copper solution is not precipitated by an alkali. The salt is sometimes called *distilled verdigris*, and is used as a pigment.

SUMMARY OF ORGANIC CHEMISTRY.

ORGANIC chemistry is the chemistry of the carbon compounds.

Organic compounds are made up mainly of C, H, O, and N.

The saturated compounds of C and H are called the *hydrocarbons*.

The *hydrocarbon radicals* are groups of atoms formed by the elimination of H atoms from the hydrocarbons. These are *positive* or *basic* radicals, whose atomicity is equal to the number of the H atoms eliminated.

The *oxygenated* or *negative radicals* are formed by the replacement of a part of the H atoms of the positive radicals by an equivalent of O.

The hydrates of the monatomic *basic radicals* are called *alcohols*; those of the *acid radicals*, *acids*.

The *oxides* of the *basic radicals* are called *ethers*; and their *salts*, *compound ethers*.

The hydrates of the *diatomic* basic radicals are called *glycols*; and those of the *triatomic* basic radicals, *glycerines*.

The *compound ammonias* are compounds derived from H_3N by replacing a part or all of the H atoms with the basic radicals.

The basic radicals often combine with the more positive metals.

Sugar, starch, and woody fibre are the three most important natural organic substances. They are closely allied in composition, and are made up of C, H, and O.

The most important natural vegetable acids are the *oxalic, malic, gallic, tannic, tartaric, and citric*.

The natural *fats* and *oils* are salts of glyceryl, C_3H_5 . The most important acids in these salts are the *palmitic, oleic, and stearic*.

Soap is the salt formed by replacing the glyceryl of these fats and oils with an equivalent of K or Na.

The *fixed* oils are those which cannot be distilled without decomposition. They are divided into *drying* and *non-drying oils*.

The *volatile* or *essential oils* are those which may be distilled without decomposition.

Resins are formed by the oxidation of the volatile oils.

Balsams are natural mixtures of the resins with the essential oils.

Gum resins are mixtures of essential oils, resins, and gums. The most important gum resins are *india-rubber* and *gutta-percha*.

The natural *organic bases* contain nitrogen, and are very complicated in constitution. They are all very energetic bodies. The most important are *morphine*, *quinine*, *strychnine*, and *caffeine*.

The most important organic coloring matters are *indigo*, *litmus*, *cochineal*, and *madder*.

Cyanogen, CN, forms a large number of interesting and important compounds, among which may be mentioned *prussic acid*, *potassic cyanide*, *prussiate of potash*, *prussian blue*, and *percussion powder*.

Fermentation is the breaking up of complex organic compounds by the agency of growing plants.

The most important kinds of fermentation are the *alcoholic*, producing *alcohol*, and the *acetous*, producing *acetic acid*.

Alcohol is ordinarily made from *cereal* grains by a process called brewing. The starch is first converted into sugar by the action of the diastase produced by the germination of the seed. The alcohol is separated by *distillation* from the liquor which is obtained from the fermentation of this sugar.

Wine is made by fermenting the juice of grapes.

In ordinary bread-making we have an example of alcoholic fermentation. If the fermentation be carried too far, acetic acid is formed, and the bread becomes sour.

Common ether is made by the action of sulphuric acid upon alcohol.

Acetic acid is made by the fermentation of alcohol, or from pyroligneous acid.

APPENDIX.

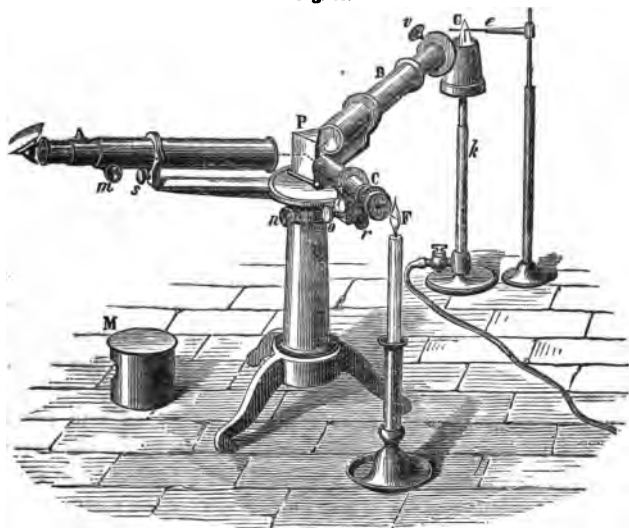


I.

THE SPECTROSCOPE AND ITS APPLICATIONS IN CHEMISTRY.

1 *The Spectroscope.* — This instrument (Figure 68) consists of a triangular piece of glass, *P*, called a *prism*, and three tubes,

Fig. 68.



A, *B*, and *C*. The tube *A* is an ordinary telescope. The tube *B* has a narrow slit in its outer end, through which a beam of light is admitted. This beam is concentrated by a lens upon the prism *P*. The tube *C* has at its outer end a fine scale marked on glass. The light from the candle *F* shines through this glass,

and is reflected by the face of the prism into the telescope *A*, so that on looking into this telescope an enlarged image of the scale is seen. The light from the tube *B*, on passing through the lens, is *dispersed* into what is called a *spectrum*, which is examined by means of the telescope *A*. With ordinary candle-light this spectrum is a continuous band of colored light, made up of the seven *prismatic colors*, red, orange, yellow, green, blue, indigo, and violet.

This simple instrument was invented in 18⁵⁹~~60~~, by two German professors, Bunsen and Kirchhoff, and it has already led to most remarkable discoveries in both Chemistry and Astronomy.

2. *Spectra of Incandescent Gases.* — The spectrum of an ordinary candle or gas-flame is called a *continuous* spectrum. If, however, we dip a platinum wire into a solution of some sodic salt, and hold it in the colorless flame of a Bunsen's lamp, so as to color it with incandescent sodium vapor, we shall get a spectrum, consisting of a single yellow line, as shown at III. in the lithographic plate at the beginning of this book. Color the flame in a similar manner with incandescent *potassium* vapor, and we get a spectrum like II. in the plate, *continuous* in the middle, with a bright line at each end. The incandescent vapors of the rare metals *cæsium* and *rubidium* give spectra like IV. and V. in the plate.

As a rule, the spectra of incandescent gases are broken, or *discontinuous*; that is, made up of bright lines separated by dark spaces. The spectrum of each element is unlike that of every other element, either in the number or the position of its bright lines, and usually in both.

The position of these lines can be ascertained with great accuracy by means of the scale, which is seen in the telescope in the same position as the spectrum; and for the same substance the position of the bright lines is always the same.

3. *Use of the Spectroscope in Chemical Analysis.* — We have now seen that, as a rule, the spectra of incandescent gases are discontinuous, and that each is peculiar to itself. No matter how many gases there may be in the flame, each will give its own lines and no others. Hence we have in the spectroscope a valuable means of recognizing the elements which exist in a

substance of unknown composition. We have merely to heat its vapor to incandescence, examine it with the spectroscope, read off the position of the bright lines on the scale, and compare it with the position of the bright lines given by known elements.

The metals of the alkalies and the alkaline earths can be readily converted into incandescent vapor, by simply holding their salts in the flame of a Bunsen's lamp, and these metals are very readily detected by means of the spectroscope. The heavier metals can be obtained in the state of incandescent gases, by passing sparks from Ruhmkorff's coil between two pieces of their salts held a little way apart; but these spectra are more complicated, and require a more powerful spectroscope (that is, one with several prisms in place of one) for examination.

This method of chemical analysis by spectrum observation is of wonderful delicacy. The .00000005 of a grain of a sodic compound can easily be detected in this way. Sodium is found to be always present in the air. All bodies that are exposed to the air show the yellow sodium line when heated. Of lithium .00000016 of a grain can be detected. This element was formerly known to exist in only four minerals: it is now found by spectrum analysis to be one of the most widely distributed of elements. It exists in almost all rocks, in sea and river water, in the ashes of most plants, in milk, human blood, and muscular tissue.

One of the first fruits of spectrum analysis was the discovery by Bunsen, in 1861, of the two new elements, *cæsium* and *rubidium*. They were found in the mineral waters of Durkheim; forty-two tons of which had to be boiled down in order to obtain two hundred grains of the metals.

It was by spectrum analysis also that *thallium* was discovered by Crookes, in 1861; and *indium*, by Reich and Richter in 1864. The spectrum of the former metal consists of a splendid green line, and its name is derived from *θαλλός* (Latin, *thallus*), a green twig; that of the latter is made up of two *indigo* bands, whence the name *indium*.

4. *Use of the Spectroscope in the Bessemer Process.* — Not only has the spectroscope proved valuable in the analysis of

chemical compounds, and in the discovery of new elements, but it has also become of important service to the manufacturer of steel. In the "Bessemer process" (page 255), everything depends upon shutting off the blast of air at just the right moment. If the blast be continued ten seconds beyond the right moment, the charge becomes too viscid to be poured from the *converter*; if it be stopped ten seconds too soon, the steel contains so much carbon that it will crumble under the hammer like cast-iron.

The flame undergoes various changes during the process, but only workmen of great skill and experience can tell by a simple inspection of the flame just when to shut off the air. By the use of the spectroscope, however, any one can tell with the utmost exactness the proper moment to stop the blast. After showing a great number and variety of bright and dark bands, the spectrum all at once becomes *continuous*, and experience has shown that this is the precise moment for shutting off the air.

5. *Use of the Spectroscope for detecting Adulterations, etc.* — When light is allowed to pass through certain solutions, as that of potassic permanganate, or through certain coloring substances, as madder, magenta, or chlorophyl, and is then examined by the spectroscope, the spectrum is found to be crossed by dark bands, called *absorption bands*. As each of these substances gives absorption bands peculiar to itself, we have in these bands a ready means of recognizing the substance, and also of detecting adulterations in a medicinal compound or in a dye-stuff. The purity of wines may thus be tested, since the coloring-matter of the grape gives absorption bands wholly unlike those of the adulterations used.

By means of the spectroscope, too, the .001 part of a grain of the coloring-matter in a blood-stain can be detected with absolute certainty. Hence, the instrument has become a most valuable aid in medico-legal investigation.

[For the applications of the Spectroscope in *Astronomy*, see the Appendix to the "Elements of Astronomy," published in the "Cambridge Course of Physics."]

II.

DISSOCIATION.

1. *Heat tends to overcome Cohesion and Affinity.*—We have seen that sensible masses of matter are made up of insensible molecules, and these molecules of yet smaller masses called atoms ; and that the atoms of a molecule are held together by affinity, and the molecules, in solids and liquids, by cohesion. We have seen, also, that heat may either partially or wholly overcome this cohesive force so as to convert a solid into a liquid or into a gas.

We have further seen that heat will in some cases break up the molecules themselves, and thus decompose the compound, as in the preparation of oxygen from potassic chlorate.

In 1857, the celebrated French chemist, Henri St. Claire Deville, first called attention to the fact that any substance may be decomposed if sufficiently heated. This spontaneous decomposition of substances under the influence of heat he calls *dissociation*. He thinks that the dissociation of compounds, like the melting of solids or the boiling of liquids, takes place at a definite temperature, which is different for each substance. Thus nitric anhydride decomposes spontaneously at the ordinary temperature ; ammoniac carbonate dissociates at 60° C., and ammonia gas at a red heat. He thinks that water is dissociated at a temperature of about 1000° C.

In the case of water, and most other compounds, the fact of dissociation is not ordinarily observable, because on cooling down the atoms reunite so as to form the original compound again. Thus, if heated above 1000° C. the vapor of water is really separated into hydrogen and oxygen atoms, but on cooling down they again unite with each other so as to form water.

It would at first seem that the theory that heat tends to overcome affinity, and to separate the atoms of a molecule as well as the molecules themselves, is at variance with certain well-known facts ; as the refusal of hydrogen and oxygen to enter into combination till heated. In this and many other cases heat seems to aid affinity rather than oppose it. A little consideration will, however, show that these cases are not really in conflict with the

theory. We must remember that the molecules of hydrogen and oxygen, as well as the molecules of water, are made up of atoms, and that these atoms must separate or *dissociate* before they can enter into new combinations so as to form new molecules. An element may, according to our view, undergo dissociation as well as a compound. At a sufficiently high temperature, all molecules, whether elementary or compound, would be broken up, and all matter be resolved into atoms. The first effect of the heat then, in the above case, is to dissociate the atoms in the molecules of hydrogen and oxygen; but as the point of dissociation of these gases is below that of water, the atoms of hydrogen thus set free combine with those of oxygen and form water. At a still higher temperature the water is dissociated, but on cooling down the dissociated hydrogen atoms unite with those of oxygen before they are sufficiently cool to reunite with each other, so as to form ordinary hydrogen gas.

If by any means the atoms of hydrogen could, after the dissociation of water, be separated from those of oxygen, we should in the end obtain ordinary hydrogen and oxygen gases.

On the 18th of March, 1861, Deville published a series of researches * upon the influence exerted by certain porous vessels upon the composition of the gases that pass through them. A porous porcelain tube was placed in the interior of a larger glass tube, and each was provided with separate gas-escaping tubes. On causing hydrogen to pass through the interior tube, and carbonic acid gas through the outer space, the two gases were found to exchange places, and an inflammable gas collected at the end of the carbonic acid tube. It thus appeared that the hydrogen passed through the pores of the porcelain tube, and was replaced by the carbonic acid. There was nothing new in this experiment, as the principle is described in Gmelin's "Chemistry," under the head of adhesion, and the subject was familiar to Priestley.

The previous experiment with hydrogen and carbonic acid was repeated with steam and carbonic acid. In a furnace capable of producing a heat of 1100° to 1300° C. he placed two tubes; through the interior tube of porous clay he forced

* This account of Deville's experiments is condensed from an article written by Professor Charles A. Joy, of Columbia College, New York.

a gentle current of steam, and through the annular space of the outer tube a stream of carbonic acid gas. A part of the vapor of water is decomposed spontaneously, or dissociated, in the tube of porous clay; the hydrogen is filtered through to the annular space (as in the previous experiment with carbonic acid and pure hydrogen), and the oxygen remains in the inner tube, mixed with a considerable quantity of carbonic acid. Deville obtained in this way one cubic centimetre of gas to one gramme of water. The separation of the oxygen is thus accomplished by physical agency. The free hydrogen at this high temperature reduces some of the carbonic acid to carbonic oxide, producing water. There is thus a loss of hydrogen in this experiment, so that the oxygen is always in excess of the quantity demanded by the formula of water. The carbonic acid also brings with it a small quantity of the nitrogen of the air. The explosive gas obtained had the following composition:—

	1.	2.
Oxygen	55.7	48.6
Hydrogen	24.3	13.1
Carbonic oxide	0.0	25.3
Nitrogen	20.0	13.0
	<hr/>	<hr/>
	100	100

It will thus be seen that Deville was able to dissociate the oxygen and hydrogen of water, and to obtain these gases in a separate condition. His experiment suggests a method for the accomplishment of this desirable result in an economical manner. By employing the carbonic acid resulting from the fire used to generate the steam, we can conceive of a simple system of tubes that would enable us to dissociate water in a way that would yield hydrogen and oxygen for light and heat.

Deville published an account of another series of experiments, February 13, 1865. He conducted these upon a somewhat different plan. He had early observed that, although compounds were dissociated at high temperatures, yet on cooling the elements recombined before they could be collected; it therefore became necessary for him to devise some plan to obviate this difficulty. He hit upon the following expedient: Through the centre of the system of tubes he arranged a tube

for conducting a constant stream of cold water. While the outer vessel was raised to the highest temperature of the furnace the inside was cold, and thus two surfaces were exposed to the gas, one for dissociating it, the other for condensing one of the constituents before it could recombine. In this way he succeeded in dissociating sulphurous acid at 1200° C. into sulphur and sulphuric anhydride; muriatic acid into hydrogen and chlorine; carbonic oxide into carbon and carbonic acid; and carbonic acid into carbonic oxide and oxygen.

On the 16th of April, 1866, Deville presented to the Academy a communication from M. Cailletet, giving an account of an important series of experiments conducted in a blast-furnace, confirming the observations previously made by Deville, and showing conclusively that the theory of dissociation is capable of extended application in the whole field of metallurgy.

2. *The Chemical Action of Light.*—Several compounds are decomposed under the influence of light. This is especially the case with the salts of silver. When these salts are in contact with organic matter and exposed to the light, they *blacken* more or less rapidly. This blackening is due to a decomposition effected by the light. Some of the silver is set free in a very finely divided state, and thus appears black. The chemical action of light is quite analogous to that of heat. In this and other cases it acts against affinity, and tends to break up the molecules of a compound.

In the case of hydrogen and chlorine, it appears to aid affinity; for if we place a mixture of these two gases in direct sunshine, they unite with a violent explosion, while in the dark they will remain mixed any length of time without combination. But here also the direct action of the light undoubtedly tends to separate the atoms from each other in the molecules of hydrogen and chlorine, so that they may combine anew to form muriatic acid. The strong disposition of the hydrogen and chlorine atoms to combine doubtless aids the light.

As a rule, the more refrangible the rays, the stronger their chemical action; but different substances are affected by rays of different refrangibility. Tyndall's recent experiments with vapors indicate that the decomposition is effected by the particular rays which the body *absorbs*.

III.

THE CHEMISTRY OF LUMINOUS FLAMES.

Until a very recent day, all scientific men laid it down as a rule without exceptions, that the light of flames is due to solid bodies or solid particles intensely heated. Frankland, in 1867, was the first to dispute this theory, and to show that there may be very bright flames in which no solid particles are present. He burned a jet of hydrogen in a tube filled with oxygen, and, gradually increasing the pressure upon the gas to twenty atmospheres, he found the brilliancy of the flame to increase with the pressure. At a pressure of ten atmospheres, a burning jet of hydrogen an inch in length gave light enough for reading a newspaper at a distance of two feet from the flame. He also found that carbonic oxide, which usually burns with a very pale flame, burned very brightly under great pressure. In the first case, the product of the combustion was *water*, which must have existed in a gaseous state in the flame; in the second case, the product was *carbonic anhydride*, which must also have been a gas. In both cases, the gas in the flame was rendered more dense by the pressure.

If arsenic be burned in a stream of oxygen gas, it yields a dazzling white flame, though neither the arsenic nor the product of its combination with oxygen can remain solid at the temperature of the flame. The same is true of sulphur and phosphorus when burned in oxygen. The latter burns with a brightness that is almost blinding, and yet the phosphoric anhydride which is produced is so readily volatilized that it can hardly exist as a solid, even at the extreme outer surface of the flame.

These facts, and many others of the same sort, prove that the luminosity of flame may sometimes be due, not to the presence of solid particles, but to that of *dense gases or vapors*, intensely heated. Frankland's experiments appear to show that, as a rule, the denser the vapor the brighter will be the flame. If the pressure of the air upon a flame is increased, it becomes more luminous; if the pressure is diminished, it becomes less luminous. The flame of a common spirit-lamp grows bright in condensed air; and a candle gives more light at the foot of a moun-

tain than at its top, though the rate of combustion is nearly the same in both cases.

Are we to explain the light of an ordinary candle or gas flame in this way? Frankland believes that we should do so. Hydrogen, as we know, has a far greater attraction for oxygen than carbon has; consequently, when both are present, and the supply of oxygen limited, the hydrogen takes up the greater portion of the oxygen to the exclusion of a great part of the carbon. Now, this happens, in the case under consideration, at some little distance within the outer surface of the flame, that is, in the luminous portion; the little oxygen which has penetrated thus far inward is mostly consumed by the hydrogen, and hydrocarbons are separated, rich in carbon and of great density in the state of vapor. These hydrocarbons, which would form smoke if they were cooler, and are deposited as soot* on a cold body held in the flame, become intensely ignited by the burning hydrogen, and evolve a light whose whiteness marks a very elevated temperature. In the exterior and scarcely visible part of the flame, these hydrocarbons undergo combustion.

If the gas be previously mixed with air (as in the Bunsen's lamp) or if air be forced into the interior of the flame, the hydrogen and carbon burn *together*, forming vapors much less dense, and the luminosity almost disappears.

Such, in brief, is Frankland's explanation of the phenomena of ordinary illumination, and the teacher can use it in whatever way he pleases, in connection with the corresponding portions of §§ 425, 426, and 431. The new theory appears to be quite generally adopted by scientific men; but no one ought to be ignorant of the old one, which will continue to have at least a historic interest from the fact that it was so long universally accepted as a complete explanation of all the varied phenomena of luminous flames.

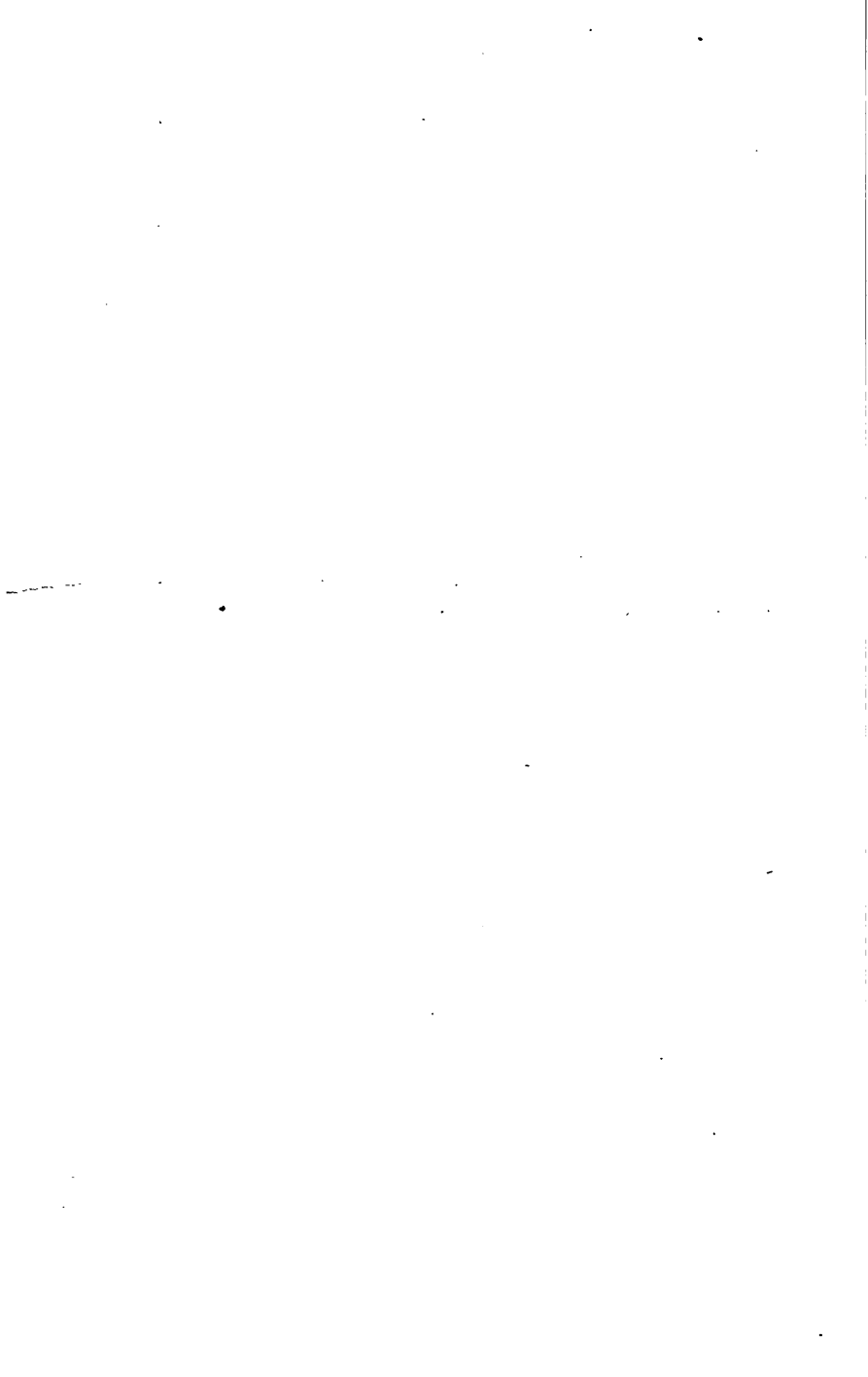
It is proper to add that Frankland does not presume to assert that the decomposition of hydrocarbons in the gas-flame is never complete, — in other words, that particles of elementary carbon are never separated, — but he is fully satisfied that "the incandescence of solid particles is not the chief condition of lumi-

* Frankland has shown that soot is not pure carbon, but a mixture of heavy hydrocarbons.

nosity," but that the light is "mainly due to the ignition of dense hydrocarbon vapors."

Certain obvious facts connected with gas-flames are perfectly consistent with this new theory, while they are not easily explained under the old one. The flame from a common fish-tail burner is so transparent that the smallest print can be read through any part of it without the least difficulty. We find, too, that the edge of such a flame gives just as much light as its flat side does. If the light proceeded from solid particles, the most luminous part of the flame ought to be more or less opaque ; and, as such particles would obstruct the light of those behind them, the edge of the flame ought to be less bright than the side.

On the whole, we must admit that some of the phenomena of luminous flames can be satisfactorily explained only by Frankland's theory, and that probably it furnishes the correct explanation of nearly all such phenomena.



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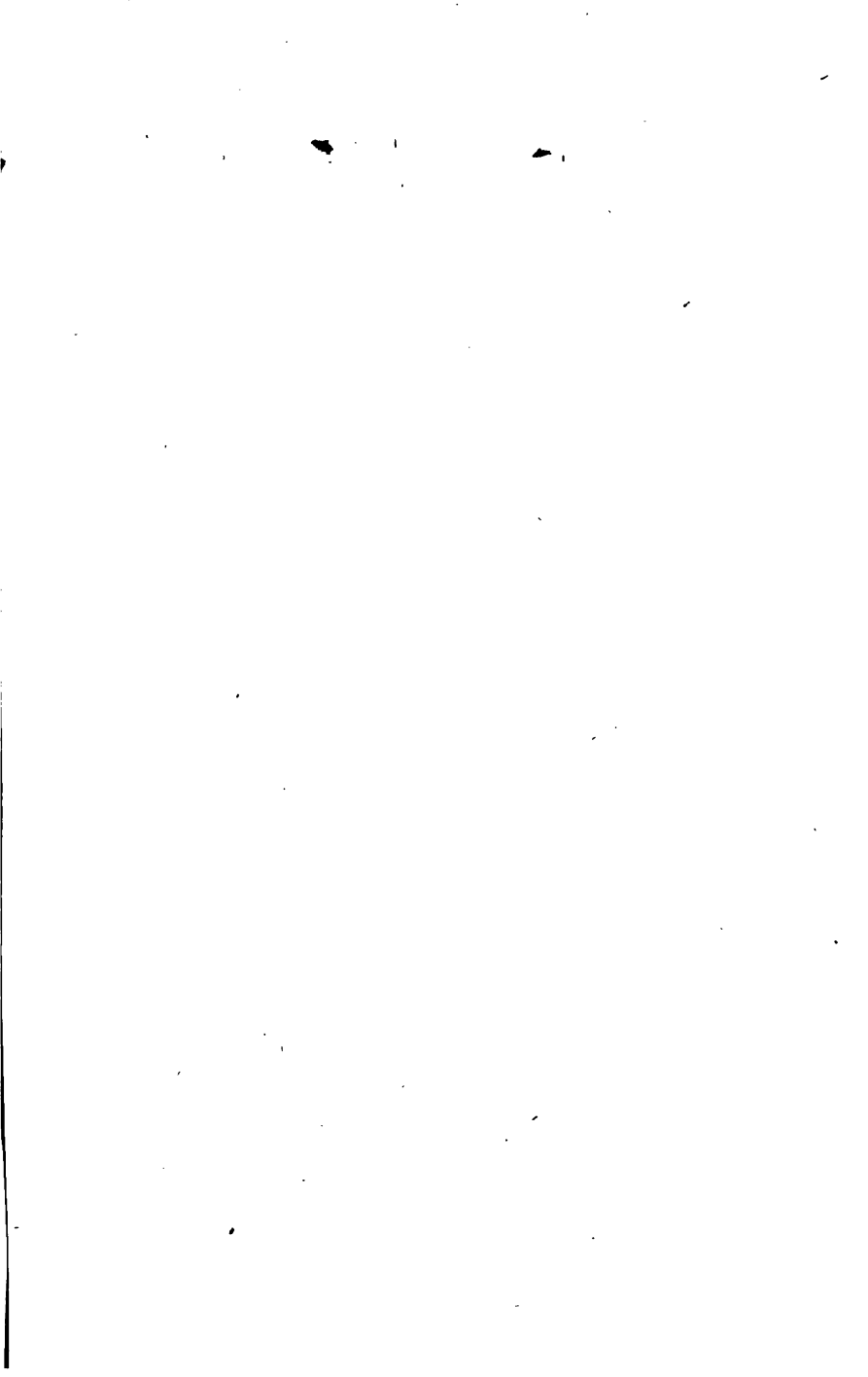
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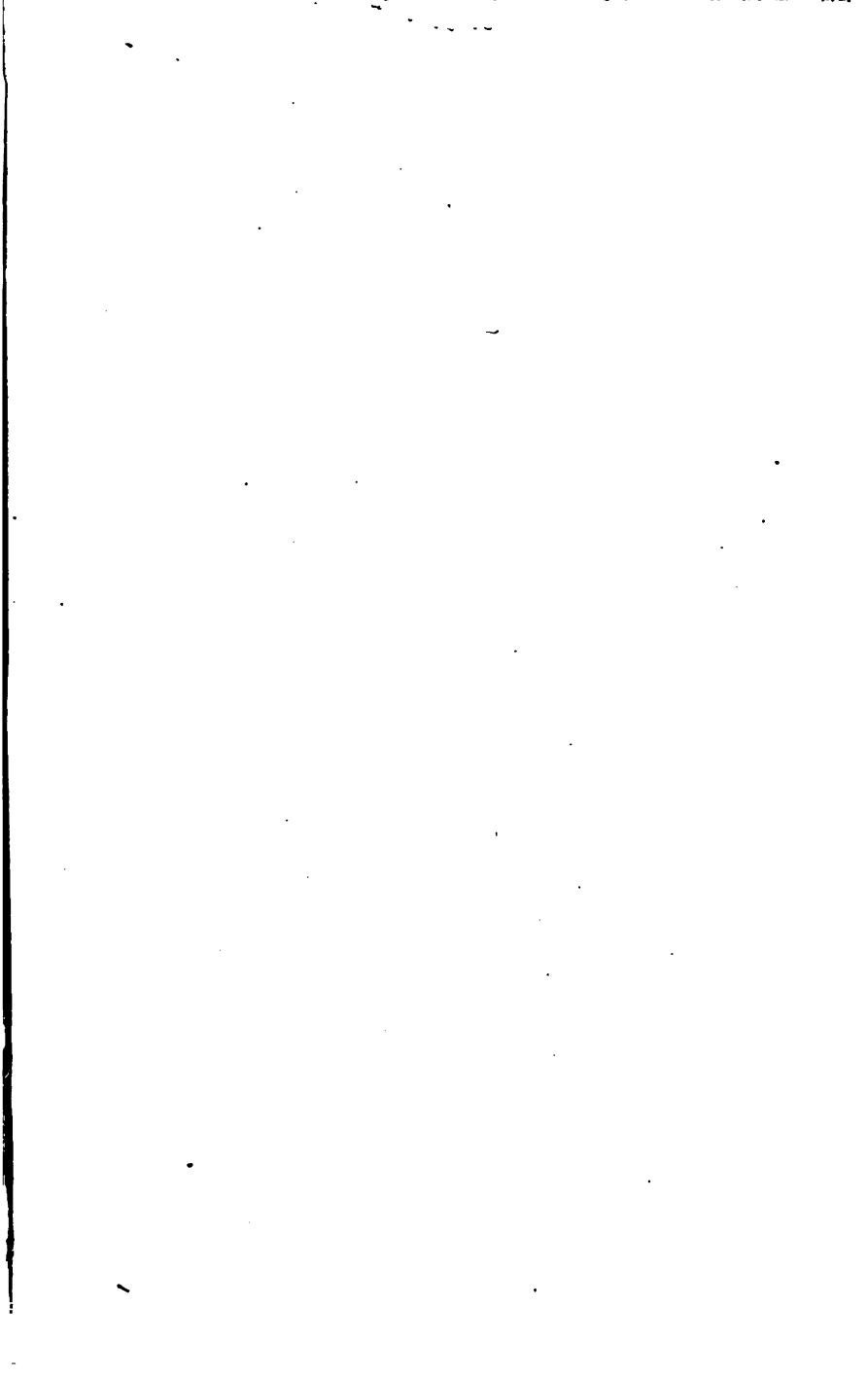
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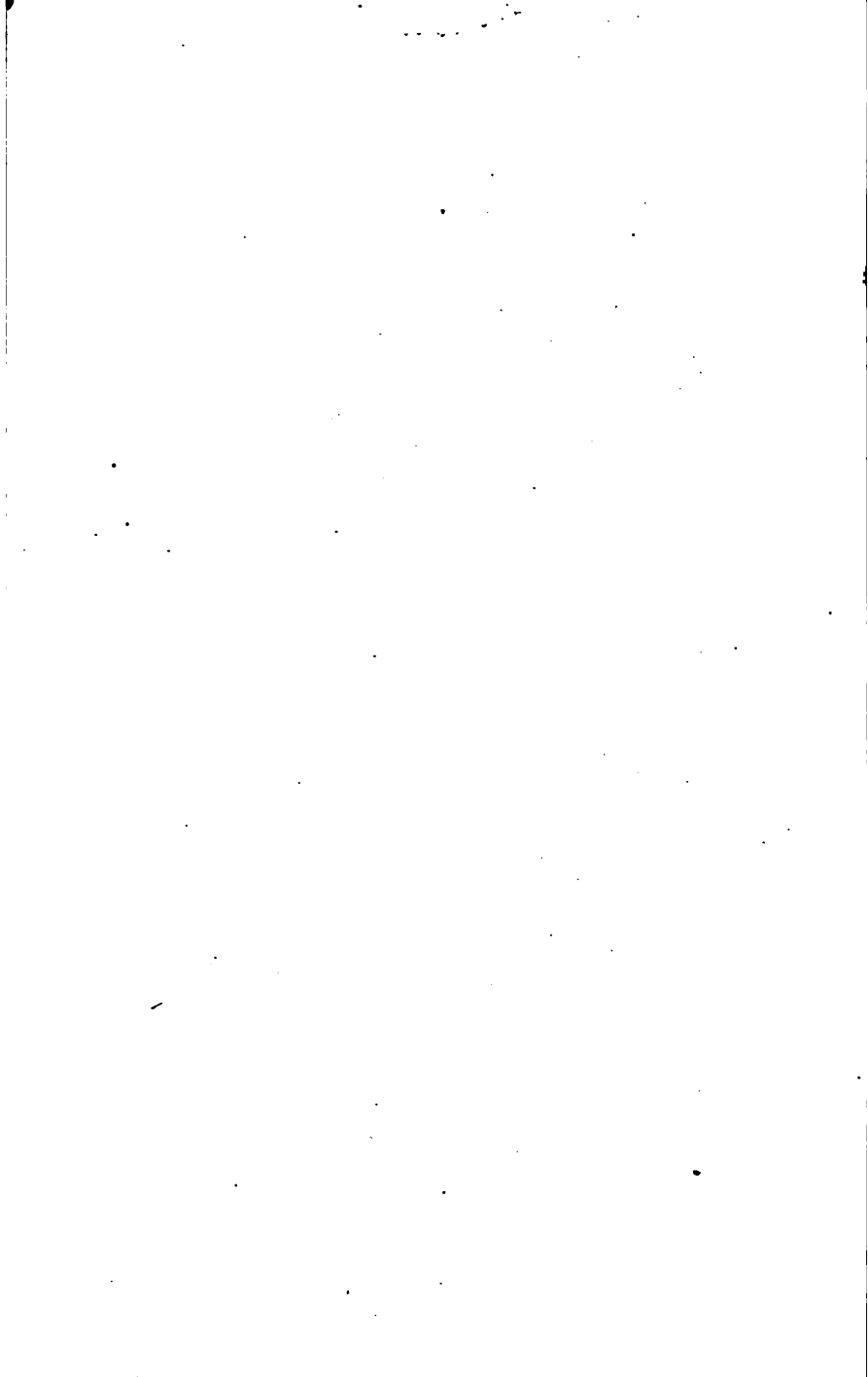
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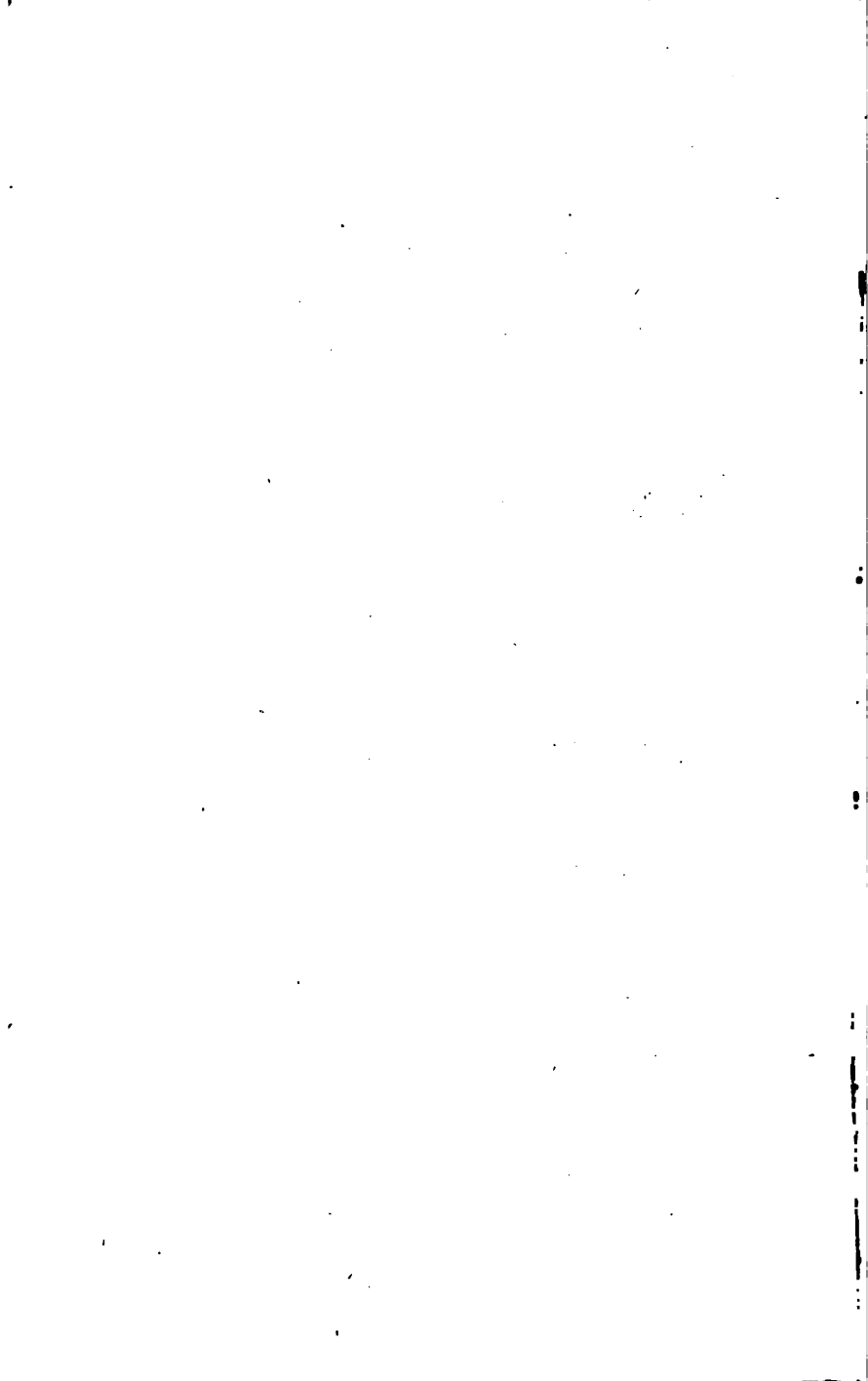
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